Ethics and Information Technology (2026) 28:49
https://doi.org/10.1007/s10676-026-09923-z

ORIGINAL PAPER

When networks sense and decide: a preliminary investigation of the human and invisible ethical dimensions of ISAC in 6G

Maria Gardano[1] · Antonio Nocera[1] · Michela Raimondi[1] · Ennio Gambi[1]

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Abstract
Integrated Sensing and Communication (ISAC) is expected to become a core capability of future 6G networks, enabling wireless infrastructures to sense physical environments and human presence through shared radio resources. While offering significant technological benefits, ISAC also raises ethical and societal concerns due to its invisible and pervasive sensing nature. This paper proposes a human-centric, questionnaire-based framework to assess the acceptability of ISAC functionalities and to operationalize ethical and societal perceptions into quantitative, design-oriented indicators. Two representative human-centric scenarios are investigated, namely domestic monitoring for Ambient Assisted Living and human motion monitoring for safety. The proposed framework directly quantifies selected 6G human-centric values, including trustworthiness and regulation, and identifies additional design requirements related to transparency, user control, and system understanding that significantly influence acceptability. The results show that ISAC acceptance is strongly context-dependent and driven more by governance, trust, and knowledge than by sensing capabilities alone. By translating user perceptions into actionable indicators and design requirements, this work provides a practical contribution toward ethical-by-design ISAC development, complementing traditional performance metrics and supporting the realization of transparent, trustworthy, and socially acceptable 6G networks.

Keywords Integrated Sensing and Communication (ISAC) · 6G network · Ethical-by-design · Human-centric design · Key Value Indicators (KVI) · User trust · Transparency and regulation

Introduction

Integrated Sensing and Communication (ISAC) not only challenges the technological limits of wireless systems but also raises unprecedented ethical challenges for the forthcoming 6G era Sridhar et al. (2025). The paradigm is shifting: networks are no longer limited to the mere transport of information, but increasingly perceive the surrounding environment, infer human behaviors, and make autonomous decisions, often without the user's explicit awareness. In ISAC-enabled architectures, the communication network itself becomes an active sensing entity, performing both data transmission and environmental perception through its native radio infrastructure. From a technological perspective, ISAC aims to combine sensing and communication capabilities within the communication network itself by sharing hardware and radio spectrum resources. In this approach, the radio signal transmitted by the network is jointly designed to support data transmission while simultaneously enabling environmental perception. Unlike traditional radar systems, which rely on dedicated sensing hardware external to communication networks and whose sole purpose is sensing, such as estimating object position and velocity through the analysis of reflected echoes, ISAC achieves a functional convergence between communication and sensing at the network level. As a consequence, information typically regarded as a source of degradation

✉ Maria Gardano
m.gardano@pm.univpm.it

Antonio Nocera
a.nocera@staff.univpm.it

Michela Raimondi
m.raimondi@pm.univpm.it

Ennio Gambi
e.gambi@staff.univpm.it

[1] Dipartimento di Ingegneria dell'Informazione (DII), UNIVERSITA' POLITECNICA DELLE MARCHE, Ancona, Italy

Published online: 27 September 2026

in conventional communication systems, such as multipath components, becomes a valuable informational resource for sensing tasks. In this work, the term invisible ethics refers to the set of ethical implications arising from technological systems whose operation is imperceptible or opaque to users. Such implications include, for instance, passive data collection, the absence of explicit informed consent, hidden decision-making processes, and ethical consequences that are not immediately evident, but may have significant effects on individual autonomy, dignity, and privacy. In response to these challenges, recent research Hexa-X Consortium (2020); Hexa-X-II Consortium (2023); Chen (2025); Electronics (2021), and policy initiatives ISO & UNDP (2024) have emphasized the need to complement Key Performance Indicators with human-centric evaluation criteria, often referred to as Key Value Indicators. KVIs aim to capture ethical, social, and sustainability-related dimensions such as trustworthiness, inclusiveness, transparency, and user control, which cannot be adequately described by purely technical metrics. However, despite this growing awareness, KVIs are still predominantly treated in a qualitative or conceptual manner. In this context, a multidisciplinary and value-oriented approach to technological design is becoming increasingly essential, as highlighted by recent literature Chen (2025); Pintor et al. (2025); Atzori et al. (2023); Mehlich and Woopen (2025); Wymeersch et al. (2025); Ylianttila et al. (2020); Gardano et al. (2024, 2025). With the advancement of 6G research, the focus is progressively shifting from purely technical performance (KPIs), toward the values that can be enabled through the deployment of the technology itself, referred to as Key Values (KVs) Pintor et al. (2025), thereby reflecting its broader social, human, and ethical impact. As demonstrated by past experiences with 5G deployment, technological performance alone is not sufficient to guarantee social acceptance Stojanović et al. (2023); Balassa et al. (2024): trust and transparency play a decisive role in the adoption of pervasive communication infrastructures. It is therefore important to distinguish between KVs, which represent fundamental principles to be pursued (e.g., sustainability, inclusion, transparency), and KVIs, which are qualitative and/or quantitative metrics used to measure the extent to which such values are achieved. KVIs act as operational tools that translate abstract values into observable parameters, enabling the assessment, monitoring, and comparison of the social impact of technologies. Several studies Electronics (2021); Atzori et al. (2023); Uusitalo et al. (2025, 2021); Pintor et al. (2025); Dong et al. (2024); Mertens et al. (2024) have addressed the identification of societal and ethical values for 6G within the context of European research projects. In particular, the survey presented by Rantopoulos and Chochliouros (2024) analyzes different approaches adopted across Smart Networks and Services Joint Undertaking (SNS-JU) initiatives, as summarized in Table 1.

As highlighted in this table, SNS-JU projects show a strong convergence in the identification of high-level societal and ethical values, commonly referred to as KVs, and in some cases also discuss KVIs. However, a closer analysis reveals that most initiatives remain primarily focused on the qualitative identification or high-level categorization of such values, rather than on their systematic quantification. In particular, projects such as HEXA-X II, CENTRIC, and TRIALS-NET adopt descriptive or participatory approaches based on qualitative mappings, stakeholder engagement, or trial-based evaluations, without defining quantitative KVIs, that can be directly employed as engineering design

Table 1 Overview of SNS-JU projects addressing societal values and KVI-related evaluation approaches

Project	Main contribution	Domain	KVs	KVI Quantification Approach	Method
Hexa (2023, 2024)	Alignment of use cases with SDGs and value-driven requirements for 6G scenarios	Institutional/Industrial	✓	Qualitative only	Qualitative mapping between SDGs and use cases
FIDAL (2023); Fidal (2025)	Framework for deriving KVIs from KPIs; measurable indicators aligned with social values	Industrial	✓	KPIs-derived	KPI→KVI transformation with benchmarks and metrics
Centric (2023, 2025)	Participatory and user-centric approach to co-define KVs with stakeholders	Academic/Industrial	✓	Non-metric	Co-design and qualitative stakeholder validation
6G-INTENSE (2025)	Methodological mapping between KPIs and SDGs; semantic linkage between technical and societal objectives	Academic	✓	Partial (non-perception-driven)	Indirect semi-quantitative KPI→SDG mapping
TRIALSNET (2024)	Large-scale trials to assess societal and sustainability impact of 6G technologies on WP use cases	Institutional/Industrial	✓	Not formalized	Pilot trials, practical testing, and user feedback
This work	Value-oriented, questionnaire-based framework to derive human-centric KVIs for ISAC scenarios	Academic	✓	Perception-driven, normalized	User survey, direct KVI quantification, normalization, and statistical analysis.

requirements. Other initiatives, including 6G-INTENSE, propose indirect or partial estimations of value-related indicators, often through semantic associations between KPIs and societal objectives, rather than through autonomous, perception-driven metrics. Among the analyzed projects, FIDAL represents the only explicit attempt to introduce a quantitative treatment of KVIs; nevertheless, this quantification is fundamentally derived from existing KPIs, treating KVIs as secondary constructs inferred from technical performance metrics, rather than as independent and complementary indicators reflecting human-centric perceptions. As a result, despite a shared recognition of the importance of ethical and societal values in 6G development, a common limitation across existing approaches is the lack of a methodology that enables KVIs to be directly operationalized as primary design objectives. Beyond this comparative analysis, this work adopts a fundamentally different perspective on the role of values in technology design. The proposed approach explicitly starts from the identification of high-level human-centric KVs and their operationalization through corresponding KVIs, which are defined as target objectives of the design process. This value-oriented approach considers that the technology is conceived as a means to serve human needs and societal expectations, not as an end in itself. In this way, the design process starts from the identification and quantification of ethical and societal values, understood as long-term requirements. The definition of technical solutions and KPIs, then follows as a subsequent step, driven by those values, establishing a complementary relationship between KVIs and KPIs, in achieving the overall project objectives Wikstrom et al. (2024); Longo et al. (2020). This paradigm shift enables a top-down design methodology in which ethical principles guide technical choices, rather than being retrofitted onto pre-existing system architectures. Starting from a joint analysis of the KVs proposed for 6G and their applicability to ISAC technology, as seen in Table 2. This work builds on standardized ISAC use cases published by international standardization bodies and initiatives such as ETSI, one6G, 3GPP, 5GPPP, and ITU-R ISG (2025); ITU-R (2023, 2022); Wikström et al. (2022). Use cases characterized by a strong human-centric dimension are then selected, including scenarios involving human presence, safety-related sensing, behavioral monitoring, and assistive services. Based on this selection, a questionnaire is designed, in which each item is associated with one or more 6G KVs, contextualized within ISAC application scenarios. The objective of the questionnaire is twofold: to investigate how such values are perceived by end users and to propose a quantitative framework, together with dedicated metrics, capable of supporting their assessment already during the design phase, rather than exclusively ex post. The remainder of the paper is organized as follows. Section 2 presents the questionnaire, including the design rationale, ethical scope, and demographic classification of respondents. Section 3 describes the adopted data analysis methodology, clarifying the distinct roles of Likert-scale items, non-Likert items, direct quantitative KVIs, and design requirements. Section 4 reports the results, including demographic comparisons, descriptive insights from non-Likert questions, and the quantitative KVI outcomes derived from direct KV-to-item mapping. Section 5 discusses how the identified values and indicators can be operationally integrated into ISAC system design through measurable requirements and use-case-driven constraints, and outlines a conceptual extension toward sustainability and policy considerations. Finally, Sections 6 and 7 discuss implications, limitations, and future research directions.

Table 2 6G human centric Key Values adopted in this work, use cases, design requirements, and their association with questionnaire items

6G human centric KVs	Meaning as defined in 6G projects	Use case	Questionnaire focus
Healthier community	Improve satisfaction and access to medical services FIDAL (2023); Fidal (2025)	AAL	Q1 – Acceptance of ISAC functions at home to support elderly or vulnerable people
Safety	This value looks at the protection of humans, prevention of harm. Safety refers to the ability of a system to avoid harming human life, the environment, or private property due to its unavailability (lack of communication) FIDAL (2023); Fidal (2025); 6G-INTENSE (2025)	Safety in public places	Q2 – Acceptance of use of 6G localization and monitoring in public places for safety
Trustworthiness	This value relates to the idea that a solution is deemed trustworthy, both technically and socially. This is about building and maintaining stakeholders' trust in fellow users or governance; trustworthy infrastructures and networks; public trust in systems and authorities; trust in a behaviour or process; and trust in institution 6G-INTENSE (2025); FIDAL (2023); Fidal (2025); Hexa (2023)		Q5 – Trust in impartial and ethical behavior of 6G sensing
Knowledge	User awareness and understanding of how technologies operate, enabling informed judgment, enhancing digital literacy FIDAL (2023); Fidal (2025)		Q6 – Higher acceptance if the functioning of the technology is clearly understood
Regulation	Comply with the legal and regulatory framework imposed by the law 6G-INTENSE (2025)		Q7 – Need for clear and accessible rules on ISAC operation

The questionnaire

An exploratory questionnaire is designed to transform subjective ethical and social values, which are difficult to capture through traditional technical metrics, into measurable KVIs. In particular, the questionnaire seeks to assess perception, acceptability, and awareness of ISAC functionalities in scenarios characterized by non-aware interactions between the network and individuals. Since ISAC technologies often operate invisibly and do not require direct user interaction, ethical perception strongly depends on the understanding of the application context. For this reason, prior to questionnaire completion, participants are provided with a short informational introduction intended to ensure a minimum and homogeneous level of understanding of ISAC concepts and their potential applications within 6G networks. This approach reduces the influence of individual prior knowledge and promotes consistent interpretation of the questions. The introductory text presented to the participants is as follows: "Thank you for participating in this survey. 6G networks will not only transmit data faster but will also be able to "sense" the environment, detecting, for example, the presence or movements of people, through an invisible technology called Integrated Sensing and Communication (ISAC). This technology can be applied in different contexts, even without the user being aware of it, since it does not require direct interaction. With this questionnaire, we want to understand people's feelings towards these new functionalities. The questionnaire consists of 4 general questions and 9 relevant ones. Responses are anonymous and will be used exclusively for scientific research purposes." The introduction was deliberately formulated using neutral and non-persuasive language, so as not to bias participants' responses. The administration of the questionnaire was accompanied by a clear notice of data protection, informed consent procedures, and full compliance with the GDPR requirements (Voigt et al., 2017). All data are collected anonymously and used exclusively for scientific purposes. The questionnaire consists of 13 questions and is organized into two main parts. The first part collects demographic information to characterize the sample and enable comparative analyses across groups. The second part includes closed-ended questions designed to measure ethical perception and acceptability of ISAC functionalities. Demographic variables are collected using discrete categories and fixed intervals to support structured statistical analysis. Specifically:

- Age: grouped into predefined ranges (18–24, 25–30, 31–40, 41–50, 51–60, > 60);
- Geographical origin: classified by continent (Europe, Americas, Asia, Africa, Oceania);
- Educational level: categorized according to internationally comparable levels (no formal education, upper secondary education, post-secondary non-tertiary education, bachelor's degree, master's degree, doctoral degree);
- Gender: collected as an inclusive categorical variable, with the options female, male, non-binary, other, and prefer not to answer.

This classification enables the analysis of how socio-demographic characteristics influence the perception of ISAC technologies and supports the identification of statistically significant differences across groups. The second part of the questionnaire comprises 9 closed-ended questions, structured using two main formats: 5-point Likert-scale items ranging from "strongly disagree" to "strongly agree", and multiple-choice questions used to explore different nuances within the same ethical dimension. The questionnaire items, as introduced in Sect. 1 and described in Table 2, are designed to investigate a set of value dimensions relevant to human-centric ISAC scenarios, by explicitly distinguishing between directly measurable values, enabling values, and use-case-dependent values. In particular, some items are formulated to directly assess KVs widely recognized in the 6G literature, such as trustworthiness and regulation. In these cases, respondents' answers explicitly refer to trust in network behaviour and to the perceived need for clear and accessible regulatory frameworks. The knowledge dimension, understood as users' awareness and understanding of how the technology operates, is not treated as an autonomous KVI. Rather, it is considered an enabling value that emerges indirectly from a complex item and acts as a reinforcing factor for other values, especially trust and acceptability. Other questionnaire items are directly linked to values associated with specific application contexts. In particular, acceptance of assistive and care-related functionalities is analysed within Ambient Assisted Living scenarios, while perceptions of safety are addressed in the context of sensing in public spaces. In these cases, the responses capture a relevant component of the underlying values, without claiming to exhaust their full conceptual scope. Finally, the items addressing transparency and user control (Q3 and Q4) are not used to define standalone KVIs. Instead, they are interpreted as fundamental design requirements, providing operational guidance on information disclosure, consent mechanisms, and opt-out capabilities that are necessary to improve the overall acceptability of ISAC technologies. The questionnaire was administered in both English and Italian, using corresponding versions of the same items. Responses collected through the two language versions were subsequently merged into a single dataset for analysis.

The complete wording of the English version, including the corresponding response options, is provided in Appendix A.

Data analysis methodology

Data processing is based on a two-level procedure grounded in the value-oriented reference framework adopted in this work, which links high-level KVs defined for 6G networks to ISAC-specific use cases and their quantitative operationalization. In line with this perspective, not all questionnaire items are treated uniformly, but are analysed according to their conceptual role within the framework. First, statistical analysis of perceptions is conducted on the Likert-scale items using targeted independent-sample t-tests and effect size measures, defined a priori across conceptually meaningful and statistically comparable demographic groupings. This step aims to assess how the identified values are perceived across different user profiles, consistent with a human-centric evaluation approach. Second, quantitative KVIs are derived only for those values that are directly addressed by dedicated Likert-scale items. In particular, Trustworthiness and Regulation are treated as direct KVIs, computed from single-item responses and subsequently normalized with respect to the maximum Likert score. These indicators represent explicit ethical and governance-related expectations expressed by respondents. Other questionnaire items play a complementary role. The item related to Knowledge does not define an autonomous KVI, but is analysed as an enabling dimension influencing the acceptance of ISAC technologies. Similarly, items addressing Healthier community and Safety are interpreted in relation to specific application scenarios, namely Ambient Assisted Living and public-space safety use cases, rather than as abstract ethical values. Finally, items concerning transparency and user control are not aggregated into KVIs, but are instead used to derive design-oriented requirements aimed at improving the acceptability of ISAC systems. Non-Likert items are analysed separately and used exclusively for descriptive and interpretative purposes, supporting the contextualization of the quantitative results without affecting KVI computation.

Results

Statistical analysis on the questionnaire items

Statistical analysis was conducted on 146 valid responses to the seven Likert-scale items included in the questionnaire. Each item was measured on a 5-point scale (1–5), providing ordinal and comparable data directly associated with the subsequent construction of KVIs. The two multiple-choice questions were excluded from statistical testing and used solely for descriptive and interpretative purposes. The analysis focuses on targeted pairwise comparisons using independent-sample t-tests, defined a priori according to conceptually meaningful and statistically comparable groupings. This approach enables robust interpretation while avoiding potentially misleading comparisons across highly uneven or semantically heterogeneous categories. All statistical tests were performed using a significance level of $\alpha = 0.05$. Effect sizes were computed using Cohen's d to assess the magnitude of observed differences.

Age-based comparison

Respondents were divided into two age groups: individuals younger than 40 years and individuals aged 40 years or older. This threshold was selected to reflect differences in technological exposure, life stage, and familiarity with digital infrastructures. Independent-sample t-tests did not reveal statistically significant differences between the two age groups for any of the seven Likert-scale items (all p-values > 0.05). Effect sizes were consistently small, indicating a high degree of stability of ethical perceptions across age groups. These results suggest that core expectations, regarding transparency, user control, and acceptability of ISAC functionalities, are largely shared across different age cohorts.

Geographical comparison

To ensure statistical comparability, geographical origin was analyzed through a binary aggregation, distinguishing respondents from Europe and respondents from the Rest of the World. This grouping reflects differences in regulatory frameworks, public discourse on digital rights, and exposure to data protection policies. Independent-sample t-tests revealed statistically significant differences for the following items:

- Need for transparency: respondents from Europe reported significantly higher mean score compared to respondents from the Rest of the World ($p = 0.0067$, Cohen's $d = 0.79$), indicating a stronger demand for explicit information regarding sensing activities.
- Importance of clear rules and regulation: European respondents again showed higher agreement levels ($p = 0.0288$, Cohen's $d = 0.58$).

No statistically significant differences were observed for the remaining items. These findings suggest that expectations related to transparency and regulation are more pronounced

in regions characterized by stronger regulatory traditions in data protection and digital rights.

Education-based comparison

Educational level was aggregated into two groups: respondents holding a bachelor's degree or higher, and respondents with an educational level below a bachelor's degree. This aggregation ensures statistical comparability while capturing differences in technological literacy and critical awareness. Independent-sample t-tests revealed statistically significant differences for the following items:

- Acceptance of ISAC functionalities in domestic environments to support frail or elderly individuals: respondents with higher education levels reported significantly higher acceptance ($p = 0.005$, Cohen's $d = -0.99$).
- Trust in the impartiality of sensing-enabled networks: moderate but significant differences were observed, with higher education levels associated with greater skepticism toward network neutrality.

These results indicate that educational background plays a relevant role in shaping trust and acceptance of ISAC technologies, particularly in sensitive application scenarios.

Perception and concerns related to ISAC (Non-Likert Items)

Before the Likert-scale items, respondents were asked to reflect on how the idea of invisible network-based sensing would make them feel, in terms of perceived observation and potential discomfort. Overall, approximately 70% of respondents reported feeling observed by such technologies. However, only about 31% associated this perception with discomfort, while 39% reported feeling observed without experiencing unease. In contrast, approximately 20% of the respondents stated that they did not feel observed or uncomfortable, and a smaller fraction (approximately 10%) reported discomfort despite not perceiving themselves as being observed. These results indicate that the perception of being sensed does not automatically translate into rejection or discomfort, highlighting a nuanced distinction between awareness, emotional response, and acceptability. After completing the Likert-scale items, respondents were asked to indicate the main sources of concern related to 6G sensing capabilities, with multiple selections allowed. Privacy-related issues clearly emerged as the dominant concern, mentioned by approximately 75% of respondents, either alone or in combination with other factors. Concerns related to data transmission security were reported by about 40% of participants, while approximately 35% expressed worries regarding personal physical safety. Only a marginal fraction of respondents referred to other issues, such as political misuse or governance-related abuse, and less than 1% declared having no concerns at all. These results confirm that ethical concerns surrounding ISAC-enabled sensing are primarily centered on privacy and data protection, rather than on safety or governance issues alone. Taken together, these non-Likert responses highlight that awareness of sensing, emotional discomfort, and ethical concern are distinct dimensions, which jointly shape user perception of ISAC technologies and help contextualize the quantitative KVI outcomes.

Overall response trends

Across the entire sample, mean values of the seven Likert-scale items range from 3.13 to 4.30 on a 1–5 scale, indicating a generally positive attitude toward ISAC functionalities, provided that transparency, user control, and regulation mechanisms are ensured. At the same time, the observed differences across geographical and educational groupings highlight that trust and acceptability are not uniform and depend on contextual and socio-cultural factors.

Key value indicators results

This section reports the quantitative results obtained from the Likert-scale questionnaire items. In line with the adopted value-oriented methodology, quantitative Key Value Indicators (KVIs) are derived only for those human-centric values that are directly addressed by a single, dedicated Likert-scale item. Additional items addressing transparency and user control are instead analyzed at the descriptive level and interpreted as design requirements rather than autonomous KVIs. Item-level descriptive statistics are reported in Table 3 to support interpretation, including the identification of items that act as direct quantitative KVIs versus design requirements (Q3–Q4). Direct KVI scores derived from one-to-one KV-to-item mapping are summarized in Table 4.

Direct quantitative KVI scores

Quantitative KVIs are computed for the human-centric values of Healthier Community, Safety, Trustworthiness, Knowledge, and Regulation, each of which is directly addressed by a specific Likert-scale questionnaire item. For each item, responses are normalized with respect to the maximum Likert score to enable comparability across values and application contexts. The highest normalized KVI score is observed for Regulation (KVI = 0.840), indicating a strong and widely shared expectation for clear, accessible, and enforceable rules governing ISAC operation. This result confirms that regulatory clarity represents a foundational

Table 3 Descriptive statistics of Likert-scale questionnaire items

Questionnaire item	Mean (1–5)	σ(1–5)	Associated human-centric dimension
Q1 - Acceptance of ISAC functions at home to support elderly or vulnerable people	3.966	1.040	Healthier community (AAL use case)
Q2 - Acceptance of 6G localization and monitoring in public places for safety	3.685	1.149	Safety (public-space sensing)
Q3 - Desire to be informed when sensing is active	4.301	0.935	design requirement: transparency
Q4 - Ability to choose whether sensing is allowed	4.199	1.068	design requirement: user control
Q5 - Trust in impartial and ethical behavior of 6G sensing	3.130	1.193	Trustworthiness
Q6 - Higher acceptance if the functioning of the technology is clearly understood	4.068	1.048	Knowledge (enabling condition)
Q7 - Need for clear and accessible rules on ISAC operation	4.199	0.860	Regulation

Table 4 Quantitative KVI scores derived from direct KV-to-item mapping ($N = 146$).

6G Key Value (KV)	Item	KVI (0–1)	σ_{norm}	Interpretation
Healthier community	Q1	0.793	0.208	High acceptance; variability suggests context/person sensitivity effects.
Safety	Q2	0.737	0.230	Moderate acceptance; perceptions more heterogeneous in public-space use.
Trustworthiness	Q5	0.626	0.239	Lowest KVI; persistent concerns about impartial/non-manipulative behavior.
Knowledge	Q6	0.814	0.210	Strong enabling condition: understanding increases willingness to accept.
Regulation	Q7	0.840	0.172	Very strong and stable expectation for clear, accessible rules.

condition for the social legitimacy of sensing-enabled networks. High acceptance is also observed for Knowledge (KVI = 0.814), highlighting the enabling role of user understanding in shaping acceptance of ISAC technologies. This finding suggests that awareness and comprehension of system functioning significantly increase users' willingness to accept sensing capabilities. The Healthier Community value, associated with domestic and Ambient Assisted Living scenarios, exhibits a positive normalized score (KVI = 0.793), confirming the perceived social value of assistive ISAC applications. However, the associated variability indicates that acceptance in care-related contexts is sensitive to individual attitudes and perceived intrusiveness. Safety in public-space sensing scenarios shows a moderately lower normalized score (KVI = 0.737), reflecting a heterogeneous balance between perceived benefits and concerns. This suggests that safety-oriented sensing is conditionally accepted, depending on proportionality, justification, and contextual safeguards. The lowest normalized KVI score is associated with Trustworthiness (KVI = 0.626). This result highlights persistent concerns regarding the impartial, non-manipulative, and accountable behavior of ISAC-enabled networks, identifying trust as a particularly sensitive ethical dimension that requires sustained attention in both system design and governance.

Variability of perceptions

The analysis of normalized variability further clarifies the degree of consensus associated with each human-centric value. Regulation exhibits the lowest normalized standard deviation, indicating a highly stable and widely shared expectation across respondents. Similarly, Knowledge shows relatively limited dispersion, suggesting broad agreement on the role of understanding as a facilitator of acceptance. By contrast, higher variability is observed for Healthier Community and Safety, confirming that acceptance of ISAC functionalities in care-related and public-space contexts is strongly influenced by individual sensitivity, situational factors, and perceived proportionality. Trustworthiness also exhibits a non-negligible level of dispersion, reflecting heterogeneous perceptions regarding the neutrality and ethical behavior of sensing-enabled networks. Although not the most variable dimension, this result indicates that trust-related concerns are unevenly distributed across users and represent a critical source of ethical sensitivity.

Using key value indicators in ISAC system design

The quantitative results presented in Section 4.2 show that perception-driven indicators can support ISAC design not only as ex-post evaluation outputs, but also as design-oriented inputs. In this work, quantitative KVIs are derived only for those 6G human-centric KVs that are directly addressed by a dedicated Likert-scale item (Table 4). In parallel, additional questionnaire items related to transparency and user control (Q3–Q4) are treated as design requirements that enable acceptance and trust, rather than as autonomous KVIs. This separation supports a practical engineering interpretation: direct KVIs provide quantitative targets for key values, while design requirements translate into implementable architectural mechanisms that preserve or enhance those values during deployment.

From human-centric values to design constraints

In a value-oriented approach, high-level KVs define the ethical and societal objectives of the system, while quantitative KVIs provide measurable targets derived from user perception. To make such objectives actionable, KVIs must be translated into concrete technical parameters that can be specified, monitored, and verified in ISAC-enabled architectures. Additionally, enabling conditions highlighted by the questionnaire, such as transparency and user control (Q3–Q4), must be operationalized as explicit system mechanisms (e.g., sensing disclosure and consent management) that support acceptance and trust across contexts. Table 5 summarizes how the adopted 6G human-centric KVs can be operationalized through ISAC-oriented design parameters, and how design requirements can be embedded as implementation mechanisms.

These parameters act as proxy metrics that designers can measure, optimize, and validate during development and deployment. In particular, transparency and user control requirements translate into architectural mechanisms (disclosure and consent management) that enable acceptance and reinforce trustworthiness, while direct KVIs provide quantitative targets for the adopted human-centric KVs. This transition from values to implementable constraints is formalized by the design workflow described in the next subsection.

Integration of KVIs into the design workflow

The integration of human-centric values into ISAC system design can be structured into a four-step workflow that translates user perceptions into actionable engineering requirements:

1. *Value quantification:* computation of direct KVI scores and normalized variability from questionnaire data (Section 4.2);
2. *Criticality screening:* identification of values requiring attention based on low KVI scores and/or high dispersion (heterogeneous perceptions);
3. *KVI-to-parameter mapping:* translation of direct KVIs and enabling design requirements (Q3–Q4) into measurable ISAC-oriented technical parameters (Table 5);
4. *Embedding into specifications:* inclusion of such parameters as verifiable requirements within system specifications, validation procedures, and optimization processes.

Within this workflow, human-centric targets become implementable constraints (e.g., opt-out latency), verification metrics (e.g., auditability coverage), or architectural mechanisms (e.g., persistent sensing disclosure), allowing traditional performance KPIs to be complemented by a formalized value-oriented dimension. In such contexts, the questionnaire indicates a high general acceptability of ISAC-based assistance and care services (Healthier community), while also showing that acceptance is enabled by transparency, user control, and trustworthiness requirements. This means that AAL benefits are recognized, but long-term adoption depends on how sensing is disclosed, controlled, and governed.

The use case of elderly monitoring in ambient assisted living

A representative application of the proposed framework is provided by ISAC-based domestic monitoring systems for frail or elderly individuals, typical of Ambient Assisted Living (AAL) scenarios, highlighted in Table 6. In this context, the results of the questionnaire indicate a high overall acceptability of ISAC-based assistance and care services, coherently associated with the human-centric value of the

Table 5 Operationalization of adopted 6G human-centric KVs and design requirements into ISAC-oriented technical parameters

Value/requirement	ISAC-oriented technical parameters for specification and validation
Healthier community (AAL)	Activity/vital monitoring reliability; fall/inactivity detection latency; missed-event rate; robustness under multipath and occlusions; edge processing ratio for AAL pipelines.
Safety (public-space)	Event-triggered sensing ratio; false alarm/missed detection rate in safety monitoring; activation conditions and proportionality constraints; retention window for safety logs.
Trustworthiness	Auditability of sensing and inference; traceability of decisions (provenance); model monitoring and drift detection; misuse prevention controls; accountability logging and third-party verifiability.
Knowledge (enabling value)	User comprehension score (UX test); onboarding success rate; effectiveness of explanations (XAI usability); transparency-of-purpose score; consistency of user-facing information.
Regulation	Policy enforcement coverage; compliance evidence availability; user-facing documentation availability; access control correctness; logging completeness and purpose limitation checks.
Design requirement: transparency (Q3)	Sensing disclosure mechanisms (visual/auditory/ambient); notification latency; persistence of sensing indicators; coverage of disclosed sensing events.
Design requirement: user control (Q4)	Consent management granularity; opt-in/opt-out latency; capability to disable sensing states; per-context permissions; local override mechanisms.

Table 6 Design-oriented translation of human-centric values and enabling requirements in an ISAC-based Ambient Assisted Living (AAL) use case

Value/enabling dimension	Design objective in AAL scenario	ISAC-oriented technical metrics
Healthier community (direct KV)	Support well-being and care of frail or elderly individuals through unobtrusive monitoring and ensure timely detection of critical events	Fall detection recall> 95%; inactivity detection latency< 30s; robustness under multipath and occlusions; edge processing ratio
Trustworthiness (direct KV)	Ensure impartial, accountable, and non-manipulative sensing behavior	Auditability of sensing decisions; traceability of inference pipelines; bias monitoring; availability of third-party audit logs
Knowledge (enabling KV)	Enable informed acceptance through understanding of system behavior	User comprehension score; effectiveness of explanations (XAI usability); onboarding success rate; consistency of user-facing explanations
Transparency (design requirement, Q3)	Make sensing activity visible and intelligible to users and caregivers	Persistent ISAC sensing indicators; notification latency; coverage of disclosed sensing events; clarity index of sensing notifications
User control (design requirement, Q4)	Allow users or caregivers to control sensing activation and granularity	Consent management granularity; opt-in/opt-out latency< 1s; manual override mechanisms; sensing resolution caps

Healthier community. At the same time, the analysis reveals that such acceptability is not unconditional, but strongly enabled by complementary factors such as trustworthiness, transparency, user control, and user knowledge. These dimensions do not emerge as sources of rejection, but rather as necessary conditions that shape how sensing-based assistance is perceived, legitimized, and sustained over time.

By explicitly integrating KVIs into the design phase, it becomes possible to translate human-centric expectations into concrete engineering choices. In AAL scenarios, this enables designers to:

- limit the spatial and temporal resolution of radio-based sensing to avoid over-monitoring;
- ensure clear, persistent, and intelligible notifications about ongoing sensing activities;
- implement data access and processing policies grounded in the principle of least privilege;
- make sensing purposes transparent, verifiable, auditable, and understandable to users.

Through this process, ethical expectations emerging from user perception are operationalized into technical design decisions, reducing the risk of social rejection and fostering long-term trust and acceptance of ISAC-enabled AAL systems. The questionnaire results support this perspective: scenarios related to elderly monitoring, as well as safety-oriented applications, exhibit the highest acceptance levels, suggesting that societal response is more favorable when sensing capabilities are clearly oriented toward collective well-being and supported by adequate safeguards.

Aligning key values indicators with sustainable development goals

Beyond their role in guiding human-centric design and governance decisions, the proposed framework also supports a conceptual alignment between KVIs and broader sustainability objectives, in particular the Sustainable Development Goals (SDGs) of the 2030 Agenda (United Nations, 2015). Through a multi-level mapping (SDGs→ KVs → KVIs → technical parameters), it becomes possible to explicitly demonstrate how ISAC design choices contribute to societal objectives, such as well-being (SDG3), responsible innovation (SDG9), and transparent institutions (SDG16). A structured mapping is introduced in Table 7 linking high-level societal goals to human-centric values and to measurable technical parameters at the ISAC design stage. The proposed framework is articulated across four conceptual levels:

1. Sustainable Development Goals (SDGs): global objectives defined by the United Nations (e.g., SDG3 "Good Health and Well-Being", SDG9 "Industry, Innovation and Infrastructure", SDG16 "Peace, Justice and Strong Institutions");
2. KVs: human-centric values relevant to ISAC systems (e.g., trustworthiness, safety, regulation, healthier community), as already identified in 6G research initiatives such as Hexa-X, ETSI ISG ISAC, and the 6G-IA;
3. KVIs: quantitative or design-oriented indicators derived from proposed framework, capturing user perceptions when directly measured (e.g., trustworthiness, regulation) or acting as enabling design conditions (e.g., knowledge, transparency);
4. Measurable technical parameters: engineering metrics that can be configured, monitored, or verified to ensure compliance with the associated values (e.g., false alarm rate, explainability score, auditability index, sensing latency).

The underlying logic of this multi-level mapping is analogous to ISO/UNDP PAS 53002:2024 (ISO & UNDP 2024), which enables organizations to demonstrate their contribution to the SDGs through verifiable and auditable indicators.

Table 7 Conceptual alignment between Sustainable Development Goals (SDGs), human-centric values, indicators, and ISAC-oriented design parameters

SDG	Human-centric KV	KVI/indicator type	Relevant ISAC-oriented technical parameters
SDG 3 Good Health & Well-being	Healthier community	Healthier community KVI (quantitative); Safety acceptance (contextual)	Fall and emergency detection latency; activity recognition reliability; false alarm rate in care scenarios; robustness of radio sensing
SDG 9 Industry, Innovation and Infrastructure	Regulation	Regulation KVI (quantitative)	Availability of enforceable policies; auditability of sensing logs; stability of sensing and communication latency; compliance evidence
SDG 10 Reduced Inequalities	Inclusiveness	Acceptance variance across demographics (descriptive)	Acceptance differences across age and geographical groups; accessibility of user interfaces; inclusiveness of consent mechanisms
SDG 11 Sustainable Cities & Communities	Safety	Safety acceptance KVI (quantitative)	Event-triggered sensing ratio; proportionality constraints; false alarm rate in public-space monitoring; sensing activation policies
SDG 16 Peace, Justice and Strong Institutions	Trustworthiness	Trustworthiness KVI (quantitative)	Auditability and traceability of sensing decisions; explainability of inference models; misuse prevention mechanisms

Similarly, the proposed framework shows how human-centric values in ISAC systems can be progressively translated from abstract societal objectives into design-relevant and technically enforceable metrics. In this sense, the SDG alignment represents a conceptual extension of the framework, illustrating its scalability and relevance for responsible and sustainable ISAC system development.

Discussion and future challenges

The results presented in Section 4.2 show that the acceptability of ISAC functionalities is strongly context-dependent and cannot be inferred from technical performance alone. While assistive and safety-oriented applications are generally perceived as socially beneficial, user acceptance is systematically conditioned by the perceived transparency and controllability of sensing operations, regulatory clarity, and trustworthiness. From an interpretative perspective, these findings confirm that human-centric dimensions act as enabling or inhibiting factors for ISAC adoption. In particular, trustworthiness emerges as a critical value that cannot be assumed as an emergent property of technical efficiency, but must be actively constructed through explainability, accountability, and auditable system behavior. Similarly, the strong and stable expectation for clear regulatory frameworks highlights the role of governance as a prerequisite for social legitimacy, rather than as an external constraint imposed after deployment. The analysis also highlights the enabling role of knowledge and system understanding. Although not treated as an autonomous KVI, the strong agreement on the relationship between understanding and acceptance confirms that transparency and explainability mechanisms are central in shaping ethical perception, especially in the presence of invisible sensing capabilities. Quantifying user perceptions at the level of individual values allows designers and policymakers to identify which dimensions require targeted architectural interventions (e.g., trustworthiness) and which represent baseline expectations that must be preserved across use cases (e.g., regulation). The findings of this study should also be interpreted in light of several limitations. First, the analysis is based on an exploratory sample of 146 respondents and is not intended to provide a statistically representative characterization of the general population. Moreover, some demographic categories were aggregated to enable statistically comparable group analyses, which may reduce the granularity of the observed differences. Second, several human-centric dimensions are represented by single dedicated questionnaire items. While this approach enables a direct and transparent quantification of each considered dimension, it necessarily provides a simplified representation of potentially multifaceted user perceptions. Future studies could investigate each dimension in greater depth by considering multiple items capturing different aspects of the same construct and subsequently aggregating their results into more comprehensive indicators, thereby enabling a multidimensional quantification of the considered values. A further limitation concerns the current maturity of ISAC technology and its practical deployment. The study was conducted at a stage when ISAC and 6G technologies were still under development and standardization, prior to their large-scale deployment and integration into everyday environments. Consequently, respondents could not base their evaluations on direct experience with fully deployed ISAC-enabled systems, and their perceptions were necessarily based largely on prospective scenarios and anticipated consequences. User perceptions may therefore evolve as these technologies mature and their actual implications become directly observable in real-world applications. Finally, the study focuses on a limited set of representative human-centric ISAC scenarios, particularly Ambient Assisted Living and public-space safety

applications. User perceptions may differ in other application contexts. Looking ahead, several research challenges can be identified. A first challenge concerns the integration of the proposed framework into real ISAC deployments through field trials and living labs, enabling the observation of how user perceptions evolve during prolonged interaction with sensing technologies. A second and open challenge involves the operational quantification of KVIs during actual system usage, and not only at the design stage. Extending the framework toward a closed-loop or iterative approach would allow user perceptions to be periodically re-evaluated and compared against initial design assumptions, enabling adaptive governance and design refinement over time. Additional research directions include extending the analysis to further application domains, such as workplaces, intelligent mobility, and large-scale public infrastructures, where consent dynamics and acceptability criteria may differ significantly. Finally, aligning human-centric indicators with regulatory and standardization processes remains a crucial challenge. In this context, KVIs may serve as a shared language bridging technical design, social responsibility, and the governance of future ISAC-enabled 6G networks.

Conclusions

This work investigated the human-centric acceptability of ISAC in 6G through a value-driven questionnaire; selected items were contextualized in representative scenarios (AAL and public-space safety) to support consistent interpretation. The results provide a structured overview of how users perceive invisible sensing technologies, combining both non-Likert exploratory questions and Likert-scale evaluations.

The non-Likert items reveal that perceiving oneself as being sensed does not necessarily translate into discomfort or rejection. While a large portion of respondents reported feeling observed, only a subset associated this perception with unease, highlighting a nuanced distinction between awareness, emotional response, and acceptability. Privacy-related aspects clearly emerged as the dominant source of concern, whereas safety- and governance-related fears were less frequently reported in isolation.

The Likert-scale results indicate a generally positive attitude toward ISAC functionalities within the investigated sample, particularly when sensing is associated with assistive and care-oriented purposes. Within the investigated scenarios, acceptance is higher for assistive and care-oriented applications than for public-space safety applications, with the latter also exhibiting more heterogeneous perceptions.

Trustworthiness and regulation emerge as critical ethical dimensions: clear and accessible rules are perceived as a stable and widely shared requirement, whereas trust in the impartial and non-manipulative behavior of sensing-enabled networks remains less consolidated.

In addition, respondents reported greater willingness to accept ISAC technologies if they had a clearer understanding of how the systems operate, supporting the interpretation of knowledge as an enabling dimension of acceptance.

Building on these findings, this work makes three main contributions. First, it provides an empirical investigation of ISAC acceptability with the use of a questionnaire, grounded in concrete human-centric use cases, highlighting the context-sensitive nature of ethical perceptions associated with ISAC.

Second, it introduces a value-oriented analysis in which trustworthiness and regulation are quantified as direct Key Value Indicators derived from dedicated questionnaire items, that can be used in a value-oriented approach to technology design.

Third, it explores demographic differences in acceptance trends and ethical perceptions, identifying significant variations associated with geographical origin and educational level, while perceptions remained largely stable across the two age groups considered.

Beyond design implications, the findings suggest several considerations that may inform future policy and governance frameworks for ISAC-enabled 6G systems:

- The high importance attributed to transparency suggests that clear and intelligible disclosure of sensing activities should be considered in future governance frameworks.
- User control mechanisms, including opt-in and opt-out capabilities, should be natively supported and verifiable.
- The comparatively lower trustworthiness score highlights the importance of considering accountability, auditability, and safeguards against secondary or non-declared uses of sensing data.
- The differences observed across application scenarios suggest that future governance approaches may need to account for the specific context in which ISAC sensing is deployed, including assistive domestic environments and public-space monitoring scenarios.
- Future work could explore the continuous assessment of human-centric indicators during system operation as a complement to design-time evaluation, enabling the proposed ethical objectives to be periodically reassessed.

Overall, the findings suggest that the ethical acceptability of ISAC extends beyond technical performance and may benefit from the systematic consideration of human-centric values in design, governance, and policy frameworks. The proposed approach provides a preliminary framework that can be further validated and extended to support the

alignment of technological innovation with societal expectations in future 6G networks.

Appendix A: Full questionnaire

The complete wording of the questionnaire items and corresponding response options is reported below. The English version is presented as the reference version of the questionnaire; the Italian version used for data collection consisted of a direct translation of the same items.

A.1 English version

A.1.1 Demographic questions

1. **Age:** 18–24; 25–30; 31–40; 41–50; 51–60; > 60.
2. **Which continent do you belong to?** Africa; America; Asia; Europe; Oceania; Antarctica.

3. **What is your highest level of education?**No formal education/Did not complete primary school;

   - Upper secondary education completed (e.g., high school diploma, GED, vocational school);
   - Post-secondary non-tertiary education (e.g., technical diploma, associate degree, vocational training beyond high school);
   - Bachelor's degree or equivalent (e.g., undergraduate degree, first cycle degree);
   - Master's degree or equivalent (e.g., graduate degree, second cycle degree);
   - Doctoral degree or equivalent (e.g., PhD, professional doctorate).

4. **Which gender do you identify with?** Female; Male; Non binary; I prefer not to answer; Other.

A.1.2 Questionnaire items

The idea that the mobile network could observe or monitor what is happening around me (for example, movements or presence) without me being aware of it (I cannot see or perceive it):

Response options:

- It makes me feel observed and uncomfortable;
- It does NOT make me feel observed and does NOT make me feel uncomfortable;
- It does NOT make me feel observed but makes me feel uncomfortable;
- It makes me feel observed but does NOT make me feel uncomfortable.

The following seven items were rated on a five-point Likert scale ranging from 1 (*Strongly disagree*) to 5 (*Strongly agree*).

1. I would accept the implementation of ISAC functionalities at home if they could help a vulnerable or elderly person.
2. The use of 6G network localization and monitoring features in public places to enhance safety seems justified to me.
3. I would like to be clearly informed when the mobile network is detecting information about the environment or my presence.
4. I should have the ability to choose whether or not to allow the network to detect my presence or movements.
5. I trust that 6G networks with sensing capabilities operate impartially and without manipulative purposes.
6. I would be more willing to accept these technologies if I had a clearer understanding of how they work.
7. The idea that 6G networks combine communication and environmental sensing makes me reflect on the importance of defining clear and accessible rules for their use.

This aspect of 6G networks, which will be able to locate people and detect what happens around them (such as movements or presence), concerns me because of:

Multiple selections were allowed.

- privacy;
- data transmission security;
- personal physical safety;
- other.

Author contributions M.G. wrote the main manuscript text, made contribution to the conception or design of the work, the acquisition, analysis, and interpretation of data; drafted the work or revised it critically for important intellectual content. A.N. made contribution to the conception or design of the work, the acquisition, analysis, and interpretation of data; drafted the work or revised it critically for important intellectual content. M.R. drafted the work or revised it critically for important intellectual content. E.G. made contribution to the conception or design of the work, drafted the work or revised it critically for important intellectual content. All authors reviewed the manuscript, approved the version to be published and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding Not applicable.

Data availability Data availability is upon request

Declarations

Conflicts of Interest The authors declare no conflict of interest.

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