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Why Do Financial Institutions Underuse Satellite Data for Environmental Risk Assessment? Expert Evidence from Europe, the United States and Türkiye

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Abstract

Financial institutions need asset-level environmental information to price physical and transition risk, verify sustainable finance claims and meet new disclosure rules, yet satellite Earth observation (EO), an independent source of such information, remains marginal in practice. We ask whether this reflects a failure to recognise the information as decision-useful, frictions in acquiring and integrating it, or genuine limits on what satellites can measure. We develop a demand–use–capability gap framework and apply it to 32 financial management needs in investment management, green finance, risk analysis and insurance, mapped to 38 EO product suites. Finance specialists scored demand and use, and EO specialists scored capability in Europe and the United States; the framework was then applied in Türkiye through an exploratory expert survey of 39 respondents (780 evaluations), of whom 37 were EO data experts and providers and two represented financial institutions. Recognition and adoption gaps dominate in both settings. Hazard screening, natural-capital baselines and building exposure data are mature but underused, while emissions attribution is the only area where capability falls short of demand (2.9 against 4.0). In Türkiye, 76.7% of evaluations report medium or high demand but 39.4% report low or no use. The dominant constraint in the expert assessments is organisational. In Europe and the United States, the quality of institutions' own asset-location data appears to condition whether satellite evidence reaches risk and reporting decisions; the Türkiye responses, which reflect EO-sector perceptions, point to a similar organisational pattern, with awareness and cost the most frequently cited barriers.

Keywords: climate-related financial risk; sustainable finance; environmental disclosure; physical risk; Earth observation; emerging markets

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1. Introduction

Climate change and nature loss have become sources of financial risk that lenders, investors and insurers are now expected to measure, price and disclose. Institutional investors regard climate risk as material to their portfolios (Krueger et al., 2020), carbon exposure is reflected in stock returns (Bolton & Kacperczyk, 2021), and supervisors increasingly

test balance sheets against climate scenarios (Battiston et al., 2017; Giglio et al., 2021). Environmental factors bear on firm value more broadly (Adamo et al., 2025; Bani-Khaled et al., 2025), and nature-related risks are only beginning to enter supervisory practice (Kedward et al., 2020). All of this depends on knowing where assets are, which hazards they face and how their environmental footprint is changing, and that knowledge is usually incomplete. Company disclosures are self-reported, uneven in coverage and slow to update; environmental, social and governance (ESG) ratings built on them diverge widely across providers (Berg et al., 2022; Christensen et al., 2021); and institutional investors themselves describe the climate disclosures they receive as insufficiently precise (Ilhan et al., 2023). The resulting shortfall, often called the climate-related data gap, is now a recognised obstacle to pricing environmental risk (Alonso et al., 2024).

Satellite Earth observation (EO) is one of the few sources able to supply this information independently of the reporting entity. It measures hazards, land-use change, vegetation, water and some emissions consistently across borders and back through time (Caldecott et al., 2022; Dowell et al., 2025; Kaushik & Jabin, 2022), and recent advances in constellations, cloud processing and machine learning have widened the range of applications (Miller et al., 2024; Pranjal & Soni, 2025). Finance research has already shown that satellite data change the information environment of capital markets. Images of retailer car parks and oil storage facilities anticipate earnings announcements and official inventory reports, allow prices to incorporate that information earlier and constrain opportunistic insider trading (Katona et al., 2025; Mukherjee et al., 2021; Zhu, 2019). Publications on EO applications in finance, investment and insurance rose from 20 in 2015 to more than 400 in 2025 (Figure 1).

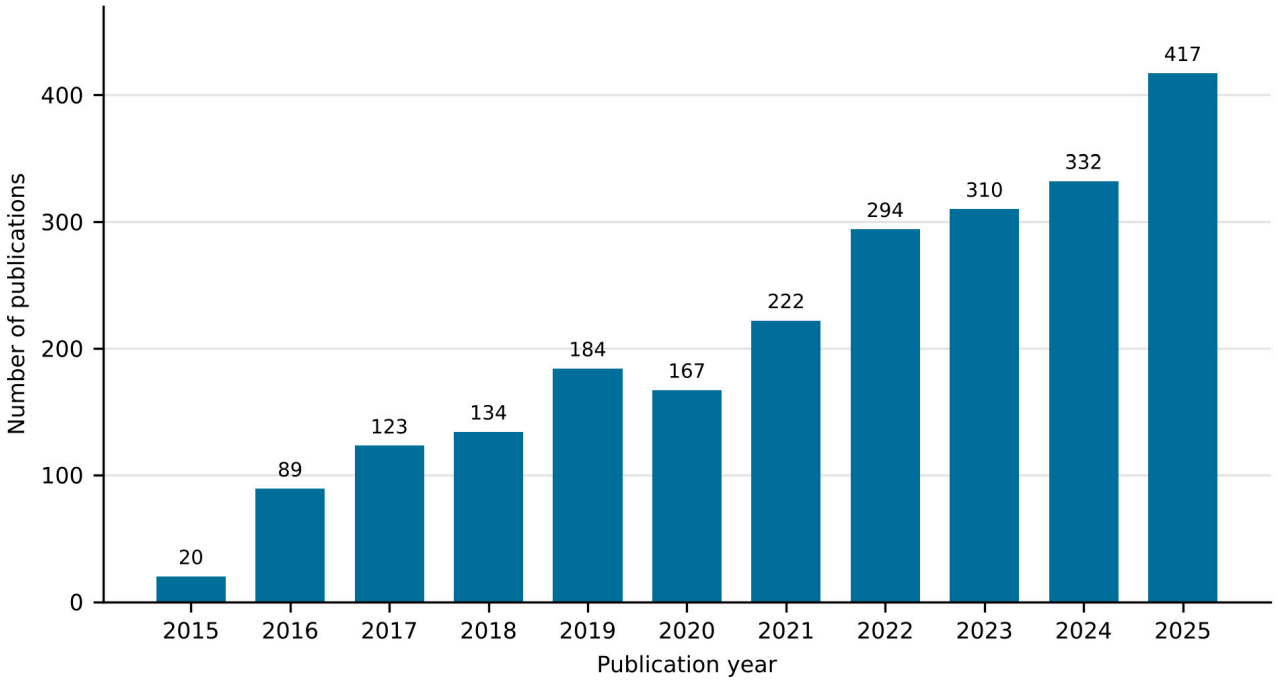


Figure 1. Annual count of publications in peer-reviewed journals addressing EO applications in the finance, investment and insurance sectors, 2015–2025, based on a Web of Science search combining "investment", "economics" or "finance" with "Earth observation" and "geospatial".

Most of that evidence concerns trading signals for listed equities. The use of satellite data in credit risk, portfolio screening, green bond verification and underwriting, where environmental information bears most directly on risk, is far less established. Practitioners report difficulty in linking environmental indicators to financially material metrics, a lack of standard processing pipelines and limited in-house geospatial expertise (Alonso et al.,

2024; Zhao et al., 2023). Uptake is concentrated in large institutions and is thin in emerging markets, although data gaps there are widest and independent evidence would be most valuable. Emerging and developing economies receive only 14% of global climate finance while bearing a disproportionate share of physical climate risk (Friedrich et al., 2024; Imandojemu, 2025).

Why the data remain underused is not well understood. The literature records low adoption but seldom identifies its cause, and three explanations compete. Institutions may not recognise that satellite evidence bears on decisions they make. They may recognise its value but find the cost of acquiring, integrating and defending it too high. Or the information they need may not be measurable at the precision that lending, investment or underwriting decisions require. Each explanation calls for a different remedy (guidance and disclosure standards, integration and capacity building, or research investment), yet the three are usually grouped together as adoption barriers, so effort can be aimed at the wrong constraint. The distinction matters to supervisors and standard setters as well as to institutions: if the dominant constraint is organisational, requiring better environmental data will not by itself close the gap.

We address this problem through three research questions. RQ1: Across financial-management domains and EO product types, where does the shortfall between financial institutions' demand for environmental risk information and their use of satellite-derived data lie, and can it be attributed to recognition, adoption friction or capability? RQ2: How does this gap profile differ between mature disclosure regimes and an emerging market exposed to external regulatory pressure? RQ3: What do the patterns imply for financial institutions, EO providers and financial supervisors?

The paper makes three contributions. First, it combines the information-economics view of costly data acquisition (Grossman & Stiglitz, 1980) with technology adoption theory to define a gap typology that separates recognition, adoption and capability constraints. Second, it applies the typology at the level of individual information needs, using 32 needs and 38 EO product suites, so that the result is a need-by-product map rather than a sector-wide generalisation. Third, it repeats the analysis in Türkiye, a market facing EU-linked disclosure and carbon border obligations with limited domestic geospatial capacity. The consolidated needs and product portfolios derive from the European Space Agency EO-FIN project; the typology, its operationalisation, the Türkiye application and all analysis reported here are original to this paper.

2. Background and Conceptual Framework

2.1. Environmental Risk Information and Satellite Data in Finance

Satellite data are already used operationally in several parts of finance, including physical climate risk assessment, deforestation monitoring, emissions tracking, agricultural risk and land-use change detection (Alonso et al., 2024). In insurance they underpin parametric flood cover, in which payouts are triggered by satellite-observed inundation extent instead of loss adjustment on the ground, reducing settlement time in markets with large protection gaps (Saunders et al., 2025; Thomas et al., 2023). In agricultural lending and index insurance, vegetation indices model yield variability and support credit assessment for smallholders who lack formal financial histories (Nguyen et al., 2025).

Satellite evidence also addresses weaknesses in corporate and macroeconomic reporting. Independent monitoring of greenhouse gases, and of methane in particular, has revealed large discrepancies between observed and self-reported emissions, with consequences for carbon-market credibility and for the pricing of transition risk (Dogniaux et al., 2025; Mehrdad & Du, 2025; Mohammadimanesh et al., 2025). Night-time lights and machine-learning analysis of daytime imagery estimate economic activity where official

statistics are weak (Beyer et al., 2022; Lehnert et al., 2023). Evidence that physical climate risk is priced in European markets (Bua et al., 2024) raises the value of measuring that risk at the scale of individual assets, which EO increasingly allows (Zhao et al., 2023).

Two strands of work bear directly on this study. Spatial finance treats geospatial evidence as a distinct input to financial analysis and has begun to formalise how asset-level environmental data enter valuation and risk models (Caldecott et al., 2022; Gopal & Pitts, 2024). A second strand catalogues supply: Rapach et al. (2024) classify EO data types by their relevance to sustainable finance, and Pinto-Gutiérrez and Arzú (2025) review the growth of the field. Both describe what satellite data could offer. Neither measures how far that offer is from what financial institutions actually use, or explains the difference.

2.2. Why Available Information Goes Unused

Finance theory has a ready account of why useful information may go unused. When information is costly to acquire and process, market participants acquire it only to the point at which its expected benefit covers the cost (Grossman & Stiglitz, 1980). For satellite data these costs are considerable: licences for high-resolution imagery, specialised staff, pipelines that join observations to holdings, and the work of making outputs defensible to auditors and supervisors. Disclosure regulation changes the benefit side of the calculation. Mandatory sustainability reporting raises demand for verifiable environmental information (Christensen et al., 2021), and investors who value climate disclosure also find what they receive imprecise (Ilhan et al., 2023). Where mandates are weak, the business case for bearing these costs is thinner.

The technology adoption literature adds an organisational mechanism. Rogers (2003) identifies relative advantage, compatibility, complexity, trialability and observability as the attributes that govern diffusion, and compatibility with existing workflows and observability of benefit correspond closely to the constraints financial institutions report. The unified theory of acceptance and use of technology (Venkatesh et al., 2003) separates performance expectancy from facilitating conditions, meaning the organisational and infrastructural support without which use cannot occur. A satellite product may be expected to perform well and still go unused because asset registries, ingestion pipelines and audit procedures are missing.

Absorptive capacity theory holds that a firm's ability to recognise, assimilate and apply external knowledge depends on its prior related knowledge (Cohen & Levinthal, 1990). This accounts for a recurring observation in the EO literature that institutions without geospatial expertise both underrate satellite products and struggle to deploy them once acquired. Recognition and cost constraints are therefore linked: low prior knowledge depresses expressed demand and raises the cost of adoption at the same time.

Applied EO studies arrive at similar categories. Borges et al. (2023) find institutional embedding, more than data availability, to be the limiting factor in national risk-reduction systems; Alonso et al. (2024) document the difficulty of linking satellite indicators to financially material metrics; and Mayr et al. (2019) and Schmitt et al. (2023) examine the validation and training-data limits that decide whether a product can support a defensible decision. The five-dimension scheme of Manunta and Coulson (2024) comes closest to a diagnostic structure, but it is framed as a checklist of enabling conditions and does not assign a shortfall to its cause.

2.3. A Gap Typology for Environmental Risk Information

We combine these strands into three mutually exclusive gap types, each defined by the relationship among three measured quantities: demand for an information need, expressed

by finance specialists; capability of an EO product to meet that need, assessed by EO specialists; and current utilisation, reported by finance specialists.

A guideline gap arises where capability exceeds demand. The information can be produced, but financial users do not see it as relevant to a decision and so do not ask for it. In Rogers' terms the relative advantage is not observable; in financial terms the information is not recognised as material. Absorptive capacity theory predicts that this gap will be widest where prior geospatial knowledge is lowest. The appropriate response is guidance, standards and worked examples that connect the evidence to specific credit, investment or underwriting decisions, and further technical development will not help. We use 'guideline gap' for the measured configuration in which capability exceeds demand; 'recognition' for one interpretation of it, that users do not see the information as decision-relevant; and 'awareness' for a barrier reported in the qualitative evidence, namely limited knowledge of which products exist and how they apply. The three are related but not identical: a guideline gap is a configuration, and recognition and awareness are possible accounts of it.

A utilisation gap arises where capability and demand are aligned but use lags both. The need is recognised and a product can meet it, but the cost of acquiring, integrating and validating the information exceeds its perceived benefit to the institution. Licensing, integration effort, perceived reliability, regulatory uncertainty and skills shortages are the facilitating conditions, in the sense of Venkatesh et al. (2003), that stop intention from becoming routine use. The response is integration support, procurement reform and capacity building.

A research and development (R&D) gap arises where demand exceeds capability. Only in this case is the constraint technological, and only here is investment in sensors, algorithms or validation methods the right remedy. The three types must be kept apart because they are conceptually distinct but easily confused; treating them together tends to overstate technological limits and to overlook recognition, cost and regulatory context. Figure 2 illustrates the three configurations. Generic regulatory and institutional barriers can suppress use regardless of the gap type and are discussed separately.

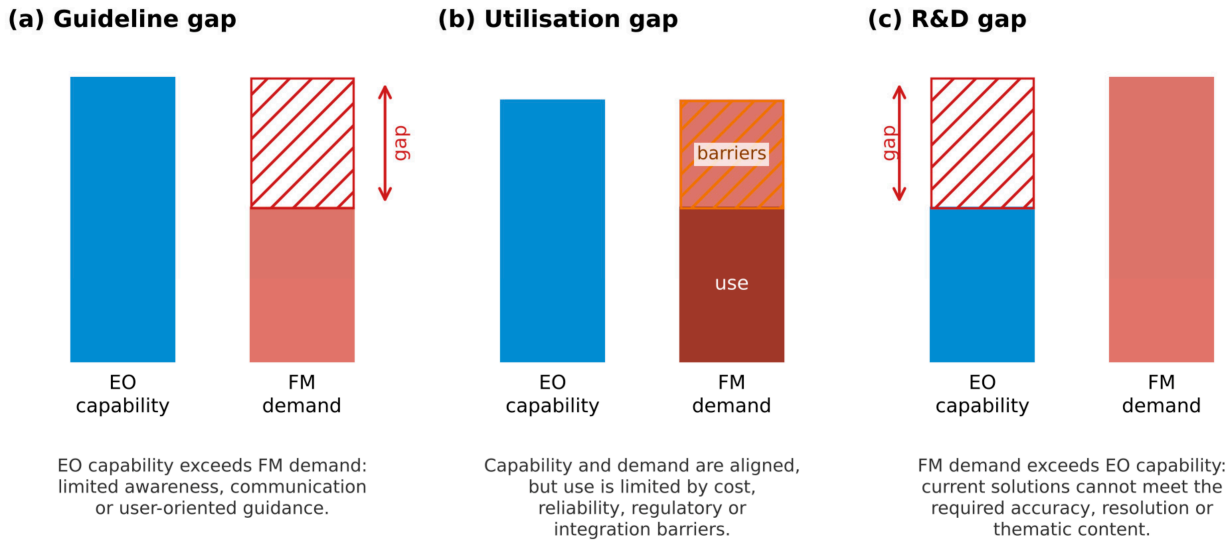


Figure 2. The three gap types. (**a**) Guideline gap, where EO capability exceeds expressed demand. (**b**) Utilisation gap, where demand and capability are aligned but operational use lags. (**c**) R&D gap, where demand exceeds current capability.

The typology adds to technology-adoption and barrier frameworks in one respect. Those frameworks explain adoption from the adopter's side and do not typically measure the technology's capability independently, so they cannot say whether non-use reflects a product that cannot meet the need, a need that is not recognised, or friction in adopting a capable product. Setting expert-assessed capability against separately elicited demand and utilisation for each need–product pair makes that distinction, so that the shortfall can be located by need and product. It locates the shortfall; it does not identify its cause or the effect of a remedy.

3. Study Contexts

The framework is applied in two settings that differ in regulatory maturity, market depth and domestic geospatial capacity but face comparable pressure to disclose climate-related information.

In Europe and the United States, disclosure regimes are established, ESG and risk reporting is mature and a commercial EO vendor market exists. Mandatory climate-related disclosure, EU Taxonomy alignment and green bond verification standards have created demand for independent environmental evidence that issuer self-reporting cannot supply (Alonso et al., 2024; Antolín-López & Ortiz-de-Mandojana, 2023), and divergence among ESG rating providers has strengthened the case for data that can be observed independently (Berg et al., 2022; Chopra et al., 2024). Institutions here generally know that satellite data exist. The open questions concern procurement, integration and audit-readiness.

Türkiye sits between these conditions, which makes it informative. Its exporters face EU carbon border adjustment reporting obligations, in force since 2023, and domestic Türkiye Sustainability Reporting Standards (TSRS) modelled on the International Sustainability Standards Board (ISSB) framework (Tyson & Seçkin, 2024), while its financial market shows the structural constraints of an emerging economy with limited geospatial capacity. The inaugural sovereign green bond, issued in 2023 and more than three times oversubscribed, shows strong investor appetite for Turkish climate assets, yet the means of independently verifying those assets' climate performance remain less developed than for comparable European issuers (Herdem Attorneys at Law, 2025). Physical geography also shapes which products are locally material and informed the selection of the survey instrument (Section 4.6).

4. Materials and Methods

4.1. Research Design

The study employs a mixed-methods design combining structured expert elicitation, multi-criteria assessment and qualitative content analysis, applied sequentially in two contexts. The workflow comprises six stages: consolidation of financial institutions' environmental information needs; consolidation of EO product suites; construction of a many-to-many mapping between them; elicitation of demand, utilisation and capability scores; classification of each need–product pair into a gap type; and qualitative interpretation of gap drivers (Figure 3). Scores without explanation cannot distinguish a cost barrier from a trust barrier, and explanation without scores cannot indicate which barriers are most widespread.

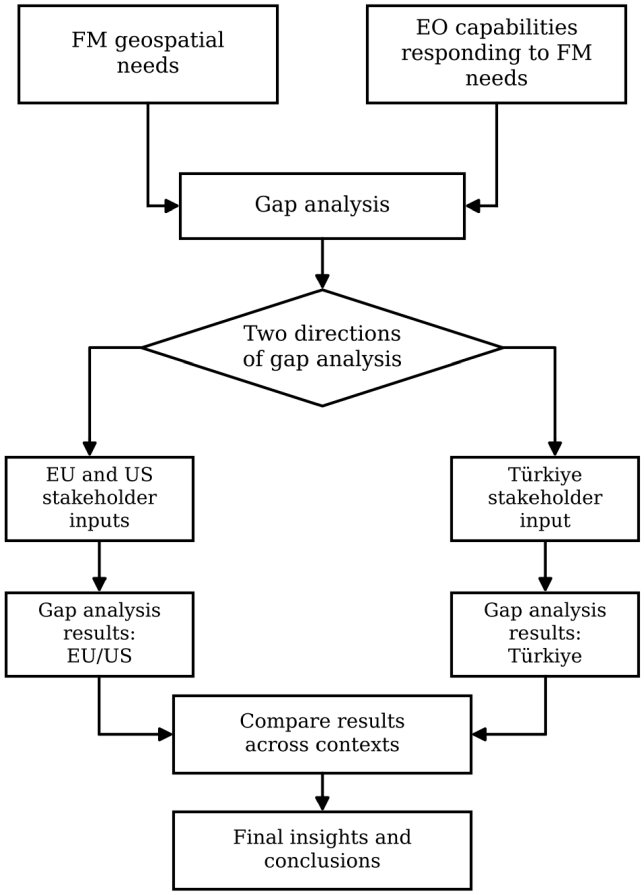


Figure 3. Workflow of the gap analysis, from consolidation of demand-side and capability-side reference sets through multi-criteria scoring to gap classification and qualitative interpretation.

4.2. Information Needs and EO Product Suites

Information needs were consolidated across four financial-management (FM) domains: investment management, green finance, risk analysis and insurance management. These domains correspond to the main points at which environmental information enters financial decisions, namely portfolio construction and screening, use-of-proceeds verification, credit and market risk assessment, and underwriting and claims. Requirements were harmonised into 32 user needs (UNs), stated without technical parameters so as not to presuppose a particular EO solution, drawing on the ESA EO-FIN evidence base and additional stakeholder engagement conducted for this study. Identifiers keep the numbering of the source requirement register, from which duplicate and out-of-scope entries were removed, so they run beyond 32 (Supplementary Table S1).

Capability-side evidence was compiled as high-level product suites rather than vendor-specific implementations, since multiple implementations may exist within a family and vary by sensor, algorithm, validation maturity and delivery model. Assessing at suite level avoids conflating the capability of the underlying technique with the characteristics of a single commercial offering. The portfolio comprises 38 suites spanning hazard and climate indicators, land and ecosystem monitoring, built-environment and exposure layers, agriculture, maritime and supply-chain proxies, and emissions-related products (Supplementary Table S2).

Products and needs relate many-to-many. A single need may draw on several products: flood-related credit or underwriting decisions use hazard layers, precipitation indicators, terrain derivatives, land cover and exposure layers. Conversely, one product family may serve several needs, as land cover does for ESG screening, biodiversity proxies, hazard exposure and urban expansion monitoring. Products become decision-relevant only when joined to asset registries and portfolio holdings, boundary and demographic layers, and hazard models. Gaps were therefore identified pairwise for each need–product link, so the same product can show different gap types under different needs.

4.3. Expert Elicitation and Participants

Scores were obtained through structured elicitation from two separate expert communities, with roles deliberately separated so that no single group assessed both the need and the solution (Figure 4). Demand inputs were gathered through workshops and interviews with FM experts across private, public and third-sector organisations. Utilisation and capability inputs were collected through separate questionnaires completed by FM and EO experts respectively, with written reasoning requested alongside each rating.

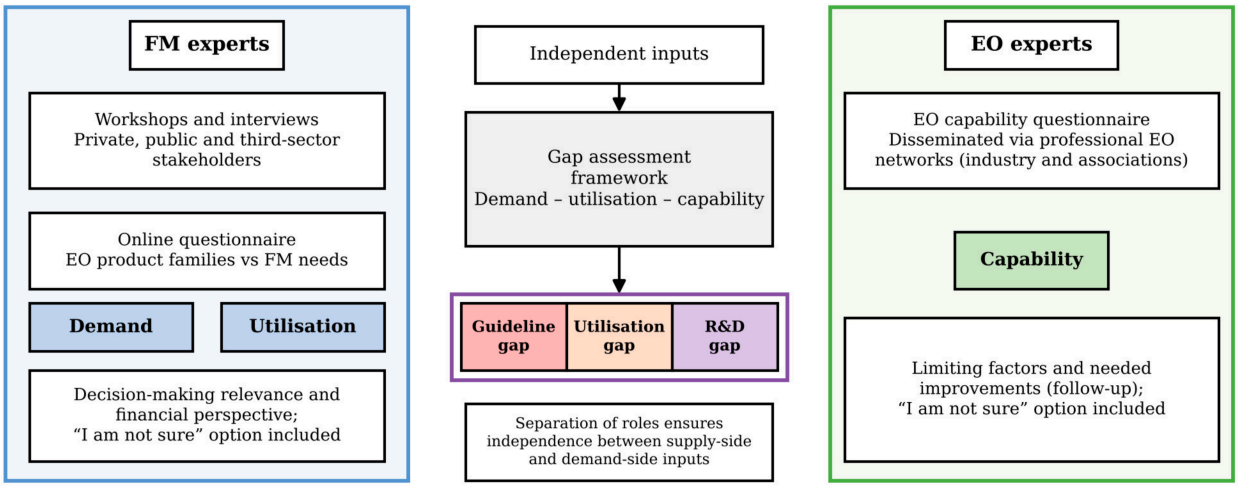


Figure 4. Separation of expert roles in the elicitation design. Demand and utilisation are scored by financial management experts; capability is scored by Earth observation experts.

The design follows established guidance for structured elicitation, which emphasises deliberate expert selection, a documented and pre-tested protocol, and awareness of overconfidence and anchoring (Morgan, 2014; O'Hagan, 2019). Separating demand and capability scoring across communities limits the risk that a single respondent rationalises need and solution jointly, and requiring written reasoning provides an audit trail against which anomalous scores can be checked.

Europe/US evidence was gathered through workshops and semi-structured interviews with FM and EO professionals recruited through the EO-FIN stakeholder network on the basis of documented professional experience in the relevant domain. Participants were drawn from private, public and third-sector organisations spanning the four FM domains, and no participant contributed scores to both the demand and the capability criteria. Utilisation was scored by 8 FM experts, each rating a median of 28 products (range 12–39) after excluding 'not sure' responses. Capability was scored by 11 EO experts, each rating all 39 products in an online questionnaire, and by 5 participants in a workshop questionnaire covering 30 products. After excluding 'not sure' responses, each product received a median of 5 utilisation ratings (range 2–8), 6 questionnaire capability ratings (range 3–10) and 4 workshop capability ratings (range 1–5); 'not sure' accounted for 31%, 43% and 23%

of utilisation, questionnaire capability and workshop capability ratings respectively. An explicit 'I am not sure' option avoided forced responses and allowed respondents to decline products outside their expertise, and mean scores were computed excluding uncertain responses. Demand was elicited from FM experts in a workshop and 2 interviews. The workshop was online and had 91 sign-ups and 63 unique attendees from 24 countries including 10 EU countries; by a categorisation made at sign-up, 28% were finance professionals, 19% consultants, 19% researchers, 17% institutional and 17% supply-side, and the United Kingdom (22%), the United States (18%) and Spain (13%) accounted for over half.

4.4. Scoring Scheme

A multi-criteria assessment was used to quantify alignment between needs and product suites, an approach suited to comparing alternatives against several non-commensurable criteria where structured expert judgement rather than measured performance data constitutes the evidence base (Belton & Stewart, 2002). Three criteria were used: demand, the interest and recognition expressed by FM stakeholders for a need; utilisation, the current level of adoption of the product family in FM practice; and capability, the ability of that family to meet the relevant needs. Each was scored on a four-point ordinal scale with anchors defined in Table 1 and circulated in advance.

Table 1. Scoring anchors for demand, utilisation and capability.

Score	Level	Demand	Utilisation	Capability
1	None	No interest or recognition of the need	Not used in the FM sector	Cannot respond to the requirement
2	Low	Limited interest or awareness	Free or basic products without EO providers (e.g., free DEM at 30 m)	Limited response; major constraints remain (e.g., new sensors required)
3	Medium	Mixed views; partially recognised benefits	Commercial products, but not best available (e.g., commercial DEM at 10 m)	Often fulfils demand but with thematic, accuracy or delivery limitations
4	High	Strong and consistent demand for solutions	Best available commercial EO services and products	Meets current and anticipated needs; standards and training can improve uptake

The scale is ordinal and intervals between adjacent levels cannot be assumed equal (Jamieson, 2004). Demand was elicited at the level of the user need, since stakeholders express a need independently of which product might serve it, and a demand score therefore takes a single value repeated across every product mapped to that need; utilisation and capability were elicited per need–product pair and reported as means across respondents. Demand consequently appears as a whole number while utilisation and capability carry decimals, and the three criteria are not equivalent in granularity. Means summarise central tendency to permit comparison across many pairs, but no parametric inference is drawn from them. Standard deviations are reported alongside means, and high dispersion is treated as a substantive finding about disagreement within the expert community rather than as noise.

As an ordinal check (Supplementary Table S8), reclassifying the pairs with medians, category-based rules and top-two-box proportions leaves the ordering of gap types unchanged (guideline > utilisation > R&D), although utilisation-gap counts depend on the summary used.

4.5. Gap Classification

Gap types were assigned by comparing scores for each pair. A guideline gap was recorded where capability exceeded demand by at least 0.5 scale points; a utilisation gap where capability and demand differed by less than 0.5 and capability exceeded utilisation by at least 0.5; and an R&D gap where demand exceeded capability by at least 0.5. Pairs satisfying none of these conditions were recorded as aligned, and gaps reaching a difference of 1.0 or more as critical. Because demand is elicited at the level of the need and shared by all products mapped to it, an aligned pair indicates that, relative to the demand for the need, capability and use are of similar magnitude; it does not indicate product-specific demand or that the product is the preferred means of meeting the need. The threshold represents half a scoring level and separates meaningful from marginal divergence; it is a judgement, not an empirically derived cut-off, so pairs falling close to it are less securely classified. Reclassifying all 84 pairs at thresholds of 0.25 to 1.0 (Supplementary Table S7) leaves the ordering of gap types unchanged (guideline > utilisation > R&D), but only 35 pairs keep the same class throughout, and ten lie exactly on the 0.5 boundary; counts of individual gap types, particularly utilisation gaps, should therefore be read as threshold-dependent. The rules are mutually exclusive by construction, but the demand–capability comparison takes precedence: where demand exceeds capability by at least 0.5 and capability also exceeds utilisation by at least 0.5, the pair is recorded as an R&D gap alone, on the principle that utilisation cannot be expected to rise above what the technology can defensibly support. The classification therefore identifies the dominant constraint under the classification rule rather than every constraint present.

4.6. Türkiye Survey

A structured questionnaire was administered to stakeholders spanning EO data provision, EO analytics, EO-enabled decision support and, to a lesser extent, the financial sector itself, covering 20 of the 38 product suites. The subset reflects the highest-priority themes for the Turkish market, guided by relevance to physical risk and ESG reporting obligations under TSRS and EU-aligned frameworks and by applicability to national environmental conditions (Section 3). Wildfire danger forecasting and post-wildfire monitoring were included in view of documented wildfire exposure; coastal erosion, bathymetry and dam safety monitoring reflect the coastline and water infrastructure; and greenhouse gas emissions monitoring was retained given the EU carbon border adjustment mechanism. Excluded products comprised highly specialised infrastructure monitoring, niche or data-intensive applications, and products requiring dense in-situ training datasets unavailable at scale in Türkiye. The survey was completed by 39 respondents, of whom 37 were EO data experts and providers, most with more than five years' experience, and two represented financial sector institutions. Demand and utilisation were rated on the four-point scale with an additional "not sure" option, yielding 780 product–organisation evaluations.

Capability was not re-elicited in Türkiye. The capability criterion defined in Table 1 assesses what a product suite can deliver as a function of sensor, algorithm and validation maturity, and these are properties of the suite rather than of the market in which it is procured: a global land cover product or a methane point-source retrieval performs to the same specification in Türkiye as in Europe. Europe/US capability scores were therefore carried over unchanged for the 20 suites surveyed, allowing the full three-way typology to be applied in both contexts on a common capability baseline. The assumption is not unconditional: capability as realised locally can fall below the suite-level assessment where a product depends on dense in-situ reference data for calibration or validation. Products of that kind were for this reason excluded from the survey subset, and the consequences are revisited in Section 6.5.

Three design features constrain interpretation. The sample is dominated by supply-side respondents, so findings are informed expert proxies for financial sector conditions rather than direct practitioner evidence. The 780 evaluations are clustered within 39 respondents, each contributing up to 20 ratings, and are therefore not independent; respondent-level distributions are reported alongside evaluation-level percentages in Section 5.4. Finally, capability is carried over rather than locally elicited, so classification in Türkiye inherits any error in the Europe/US capability assessment.

4.7. Qualitative Analysis

The classification describes configurations of demand, utilisation and capability; the qualitative evidence indicates possible mechanisms behind them but does not establish causation.

Qualitative evidence was analysed to interpret gap drivers. For guideline and utilisation gaps it was drawn from the utilisation questionnaire, in which respondents selected and explained reasons for their reported level, including lack of awareness, lack of EO skills, cost, perceived reliability, regulatory constraints and absence of free sources. For R&D gaps it was drawn from EO expert feedback, workshop discussion and desk-based technical assessment, identifying limiting factors such as insufficient resolution, latency, thematic limitations and validation constraints.

Open-ended responses were analysed in two passes: a dictionary-based frequency count establishing the relative salience of barrier categories across the corpus, followed by thematic analysis to develop and define the categories (Braun & Clarke, 2006; Krippendorff, 2018). The keyword dictionary is provided as Supplementary Table S3; the counting unit was the individual mention within a response. The count was run using online software and is rule-based and reproducible from Supplementary Table S3; no manual adjustment was made to the counts. Where a response named several barriers, each mention was counted under its own category.

4.8. Ethics

The study involved non-interventional consultation with professionals about organisational practice in their own field of expertise. No personal or sensitive data were collected beyond professional affiliation and experience level, and no data permitting identification of an individual respondent were reported or deposited. Participation was voluntary and by invitation; respondents were informed of the purpose of the study and of the intended use of their responses in aggregate form, and were free to decline any item or withdraw.

5. Results

5.1. Investment Management and Green Finance

Investment management needs display a consistent pattern in which capability is moderate to high while utilisation remains lower, producing widespread utilisation gaps alongside guideline gaps for a subset of needs (Figure 5). Accessibility and location intelligence (UN11) exemplifies the guideline gap: demand is 2 while capability is 3.7–4.0 for land cover, land use and travel-time mapping, with utilisation at 2.5–2.9. These metrics are technically available but are not consistently framed as finance-relevant, which suppresses expressed demand. Agricultural productivity monitoring for investments (UN18) repeats the configuration, with crop phenology, crop type and acreage, yield and biomass, and tillage practices recording capability of 3.0–3.7 against demand of 2.

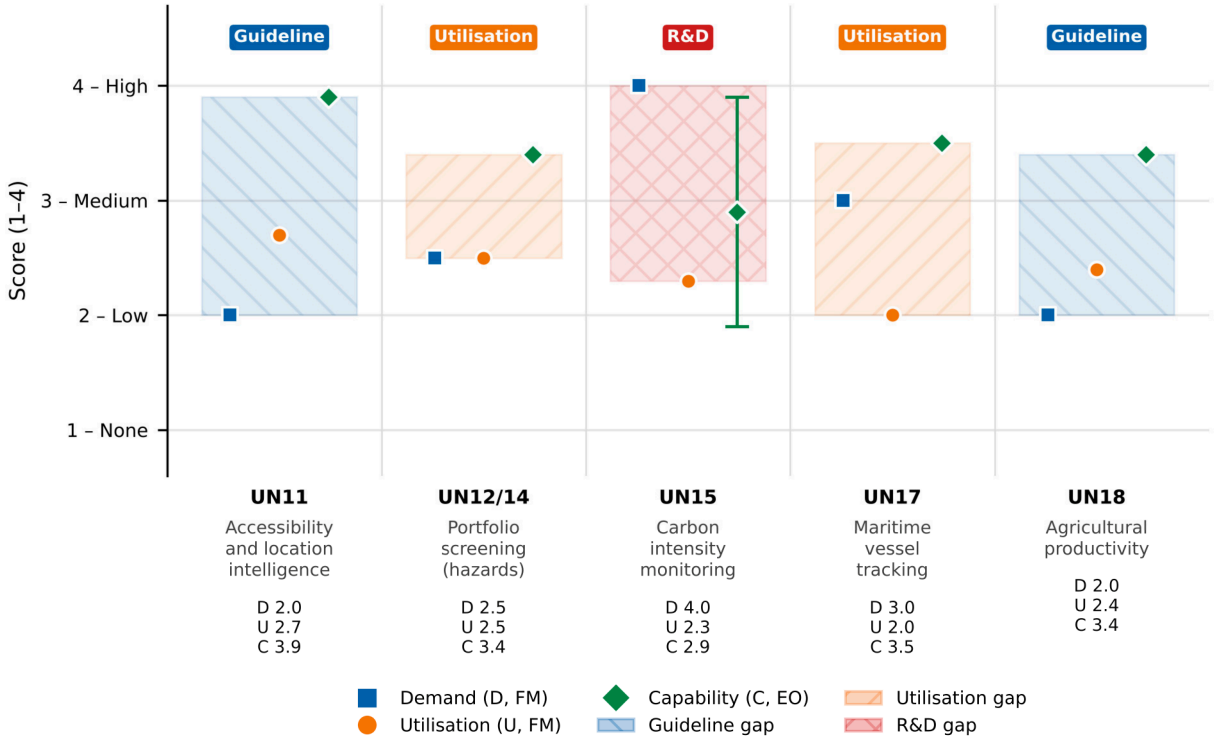


Figure 5. Investment management: demand, utilisation and capability scores by need–product pair. Markers show demand (D), utilisation (U) and capability (C); the hatched band spans the range of the three scores and its colour indicates the gap type; the whisker shows ±1 standard deviation of capability (SD ≈ 1.0) for UN15.

Portfolio screening against hazards (UN12, UN14) illustrates the utilisation gap. Flood hazard areas, drought monitoring, wildfire danger forecasting and coastal erosion record capability of 3.1–3.7 while utilisation is frequently 2.2–2.7, pointing to cost, integration and workflow readiness more than to technical feasibility. Maritime vessel tracking (UN17) shows the same structure more sharply: despite demand of 3 and capability of 3.5 for ship detection, utilisation remains at 2.0, consistent with barriers around commercial access, licensing and integration into market intelligence workflows. Carbon intensity monitoring (UN15) is the clearest R&D gap in the domain: demand reaches the maximum of 4 while the emissions monitoring family is assessed at 2.9 with high dispersion (SD ≈ 1.0) and utilisation of 2.3, the dispersion indicating disagreement within the EO community about what asset-level emissions monitoring can deliver.

Green finance needs separate into two clusters (Figure 6). Emissions monitoring for funded projects (UN26) reproduces the R&D gap, with demand of 3 against capability of 2.9; that the same constraint appears in two domains indicates a limitation that is sector-wide, not specific to one domain. Natural capital baselines and land change (UN27) show the opposite configuration, with land cover, land use and deforestation monitoring recording capability of 3.7–4.0 against utilisation of 2.7–3.0, and agricultural sustainability metrics (UN28, UN29) follow the same pattern. Tree monitoring and carbon stocks (UN30–UN32) show useful differentiation: reforestation and deforestation monitoring scores 3.9 in capability and 3.0 in utilisation, whereas tree counting and above-ground carbon stock estimation show utilisation gaps at 2.1–2.3. The distinction is not sensor capability but the validation, uncertainty quantification and auditability required for finance-grade carbon accounting.

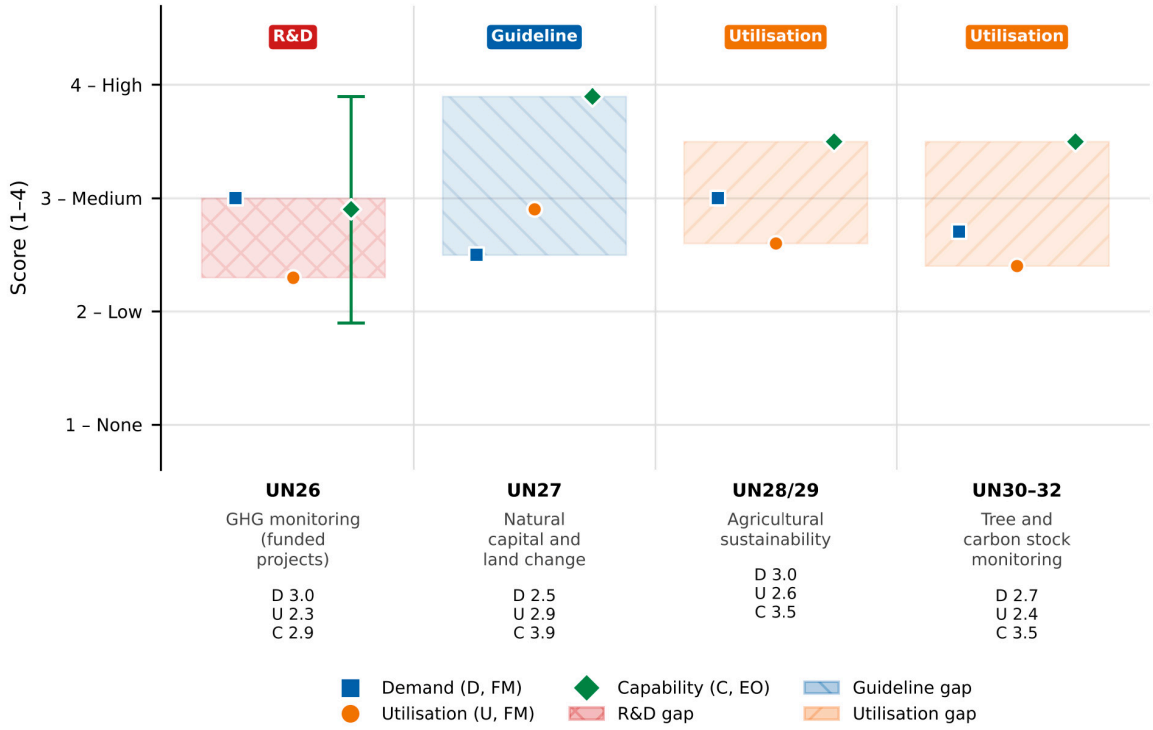


Figure 6. Green finance: demand, utilisation and capability scores by need–product pair. Symbols as in Figure 5; the whisker shows ±1 standard deviation of capability (SD ≈ 1.0) for UN26.

5.2. Risk Analysis and Insurance Management

Risk analysis is the domain in which EO relevance is most direct, yet the results show widespread guideline gaps for lower-demand needs alongside persistent utilisation gaps for exposure-related products (Figure 7). Future risk projection (UN37) records demand of 2 while associated with products including infrastructure monitoring, coastal erosion, subsidence, flood hazard areas, vegetation height and drought monitoring, most with capability of 3.2–3.7. The resulting guideline gaps indicate a framing problem: stakeholders do not consistently translate future risk projection into demand for EO-derived indicators. Ecosystems and biodiversity impact (UN39) shows the same structure, with demand of 2 against land cover maps at 4.0, deforestation monitoring at 3.9 and oil spill detection at 3.4; what is missing is guidance on which indicators map to which biodiversity questions, how materiality thresholds are set, and how outputs enter disclosure-ready reporting. Heat and drought impacts (UN41–UN42) and wildfire vulnerability and impact (UN44–UN46) follow the same pattern.

Two needs show pronounced utilisation gaps in products central to financial risk. Trustworthy time series on assets (UN38) records demand of 4 against land cover capability of 4.0 and utilisation of 2.9: mature products are not operationalised as time-series evidence aligned to asset registries, implicating integration and governance, not sensor limitations. Infrastructure exposure layers (UN47) records demand of 4 with building inventory capability of 3.6 against utilisation of 2.3, which given the centrality of exposure to financial risk assessment is among the most consequential findings in the domain. Coastal risk and sea-level rise (UN40) completes the pattern, with coastal erosion capability of 3.7 against utilisation of 2.2.

Insurance management yielded fewer mapped requirements, reflecting limited participation by insurance stakeholders (Figure 8), but the pattern is consistent. Field-scale crop damage (UN55) shows a utilisation gap, with crop health and damage detection at 3.2 against utilisation of 2.2, indicating cost, the validation standards required for claims deci-

sions, and difficulty aligning outputs with policy triggers. Building-scale land-use change (UN56) and dynamic population updates (UN57) show guideline gaps, with demand of 2 against high capability. Participation was limited partly by the commercial sensitivity of underwriting data, so these findings are directional.

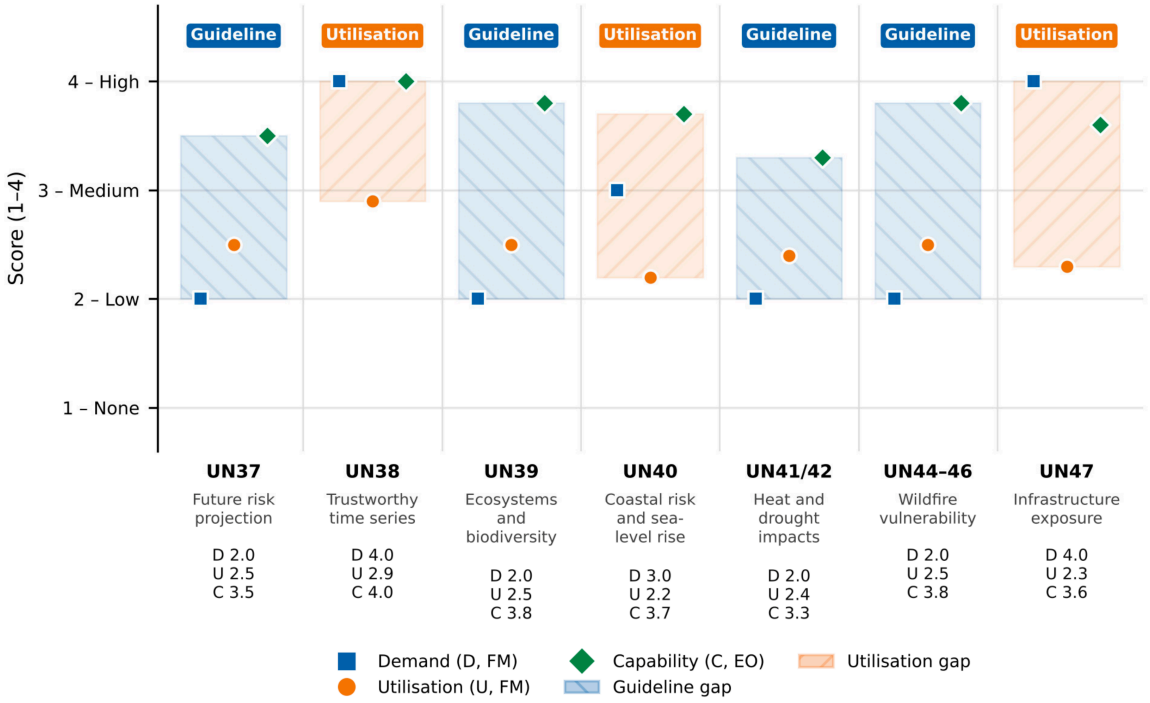


Figure 7. Risk analysis: demand, utilisation and capability scores by need–product pair. Symbols as in Figure 5.

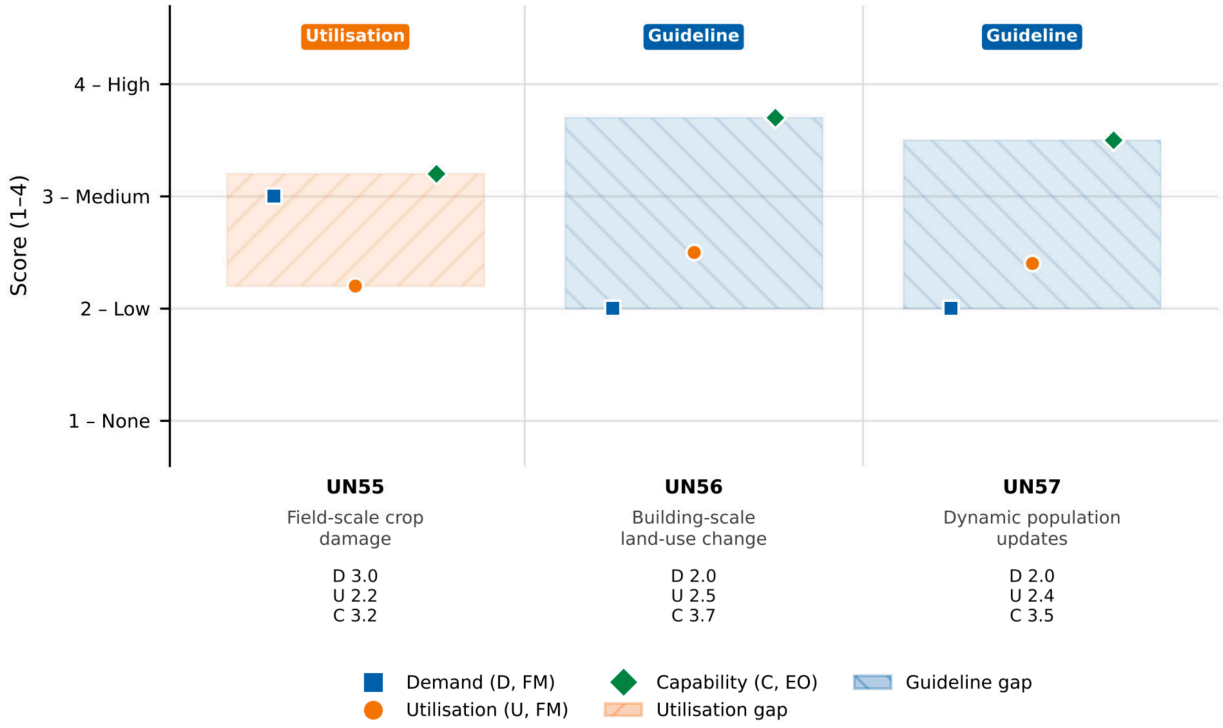


Figure 8. Insurance management: demand, utilisation and capability scores by need–product pair. Symbols as in Figure 5.

5.3. Cross-Domain Pattern in the Europe/US Assessment

Three patterns dominate. Utilisation gaps are common for finance-critical products, particularly exposure layers, coastal risk products, ship detection and certain hazard products. Guideline gaps cluster around needs with lower expressed demand, where capability is high but stakeholders do not strongly articulate the need. R&D gaps are most visible for emissions and carbon-intensity monitoring (Ding et al., 2025).

The qualitative evidence explains these configurations. Guideline gaps reflect a problem of translation and packaging, since the data themselves exist: practitioners are frequently unaware of which products exist, or cannot connect them to specific decisions, particularly for mature products such as land cover and heat hazard indicators, and responses consistently identify the absence of clear uncertainty reporting, audit trails and worked examples as the primary obstacle. Utilisation gaps are driven by the cost of commercial very-high-resolution data, limited in-house skills, insufficient integration with asset registries and internal risk models, and inability to defend outputs to auditors, regulators or clients.

A cross-cutting condition modifies all three. Foundation layers including land cover, land use and population surfaces are mature and widely recognised, yet their financial value depends on linkage to accurate asset boundaries and locations. Where asset data are incomplete, stakeholders report that detailed EO analysis adds little, which is consistent with persistent utilisation constraints even in well-established products. The contrasting case of WorldPop, already used in insurance vulnerability assessment, shows that adoption follows where a clear path from risk to decision exists (McKenzie & Slind, 2019). Product families also differ: agricultural products depend heavily on in-situ training data (Schmitt et al., 2023; Wu et al., 2023), hazard products perform well at broad scales but are limited in translating hazard into asset-level impact (Bressan et al., 2024), and economic activity proxies are constrained by resolution, coverage and cost (Zheng et al., 2023).

5.4. Türkiye: Quantitative Results

The demand distribution across the 780 evaluations is strongly right-skewed (Figure 9). Nearly half of all evaluations, 48.7%, record high demand, with a further 27.9% at medium, giving a combined medium-and-high share of 76.7%. The utilisation distribution is markedly more dispersed: although 55.5% record medium or high utilisation, 39.4% fall into the low or no utilisation categories, substantially more than the corresponding 18.3% on the demand side. Perceived value therefore does not translate straightforwardly into operational adoption.

The contingency analysis makes this explicit. Among the 380 high-demand evaluations, 72.3% correspond to medium or high utilisation, confirming predominant alignment between perceived relevance and use. However, 27.4% of high-demand cases remain at low or no utilisation, constituting a systematic demand–use gap that cannot be attributed to absence of perceived need. Medium-demand products cluster around medium utilisation at 59.2%, while low- and no-demand evaluations are almost entirely associated with low or no utilisation, at 85.1% and 77.6% respectively. ‘Not sure’ responses were excluded from the contingency analysis.

Because the 780 evaluations are repeated ratings by 39 respondents, percentages over evaluations are descriptive and should not be read as based on 780 independent observations: resampling respondents gives 95% intervals of 69.0–83.5% for medium or high demand and 31.2–47.9% for low or no utilisation, equivalent to roughly 130–140 independent observations.

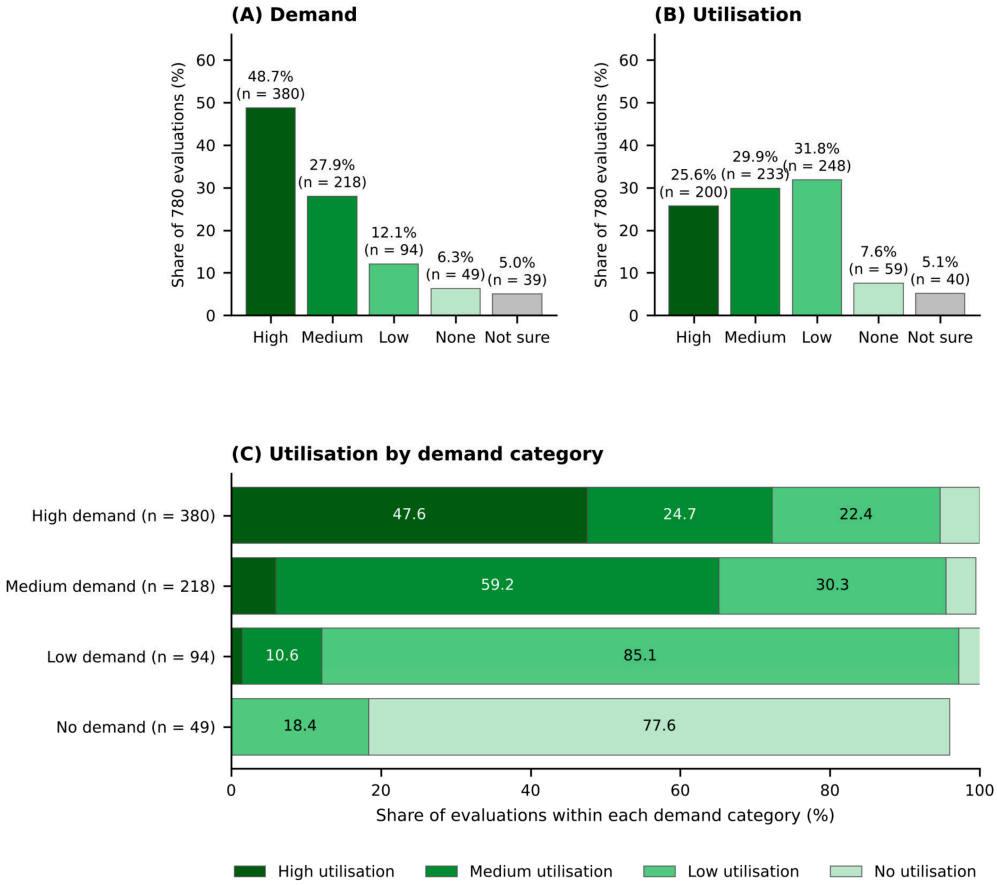


Figure 9. Demand and utilisation across 780 product–organisation evaluations of EO products, as perceived by predominantly EO-sector respondents (37 of 39). (**A**) Overall demand distribution. (**B**) Overall utilisation distribution. (**C**) Utilisation distribution stratified by demand category.

5.5. Türkiye: Qualitative Results

Open-ended prompts generated a corpus spanning 80 text fields. Dictionary-based counting shows an uneven distribution of barrier mentions: awareness-related terms dominate with 239 mentions, followed by cost-related terms at 204, while knowledge and skills references are considerably less frequent at 51, and technical concerns relating to resolution and accuracy register 7 mentions each (Figure 10). Market-facing and commercial barriers therefore outweigh product-level technical limitations and constitute the most salient constraints in this corpus.

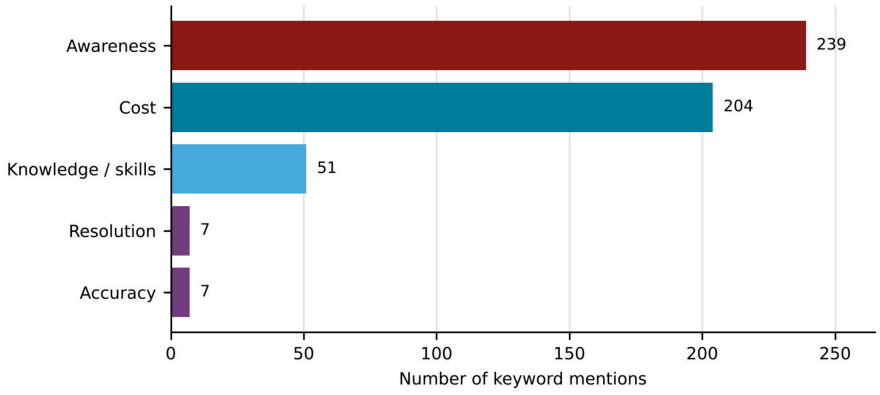


Figure 10. Frequency of barrier-related keywords in open-ended survey responses.

These counts describe salience within the Türkiye corpus only. The difference between awareness (239) and cost (204) is small, workflow integration has no dictionary entry, and no equivalent count exists for the Europe/US evidence, so the counts are not used to rank barriers or to compare contexts.

Thematic analysis identifies five categories of underutilisation (Table 2). The most pervasive is limited awareness and understanding of available products and their applicability to FM workflows, dominant among organisations reporting no or low utilisation. High cost of commercial services is the second major constraint, operating most strongly where budget pressure pushes organisations towards free or lower-specification alternatives. Insufficient internal skills restricts adoption even where interest and resources exist, and technical limitations constrain applicability for asset-level analysis, though their low keyword frequency indicates secondary salience. Workflow integration barriers confine use to pilots; this category was developed in the thematic pass and has no dictionary entry, so no count is reported against it. The counts in Table 2 are dictionary term frequencies indexing the salience of a vocabulary, not counts of respondents, and should be read as relative salience rather than prevalence.

Table 2. Thematic categories of underutilisation identified in open-ended responses.

Theme	Keyword Mentions	Description
Limited awareness and understanding	239	Respondents lack knowledge of which EO products exist, how they are structured, and how they map onto FM workflows such as credit risk or ESG screening.
High cost of commercial EO services	204	Premium pricing for high-resolution data and specialised analytics limits access, pushing organisations towards free or lower-resolution alternatives that may not meet analytical requirements.
Insufficient internal skills and capacity	51	Shortage of EO-trained personnel and limited infrastructure to process, interpret or operationalise geospatial data restricts adoption even where interest and budget exist.
Technical limitations	7	Resolution, latency and thematic accuracy constraints limit applicability for asset-level or near-real-time analysis required by operational use cases.
Workflow integration barriers	—	EO products are not embedded in existing IT systems, risk models or reporting pipelines, remaining confined to pilots or ad hoc projects.

Explanations differ systematically by utilisation level. Where medium utilisation is reported, responses describe partial adoption: use confined to specific teams or projects, continued reliance on free or lower-resolution alternatives, and budget constraints preventing access to best-available services. High utilisation is associated with a distinct set of enabling conditions (strong technical fit, trusted and well-documented sources, and clear alignment with compliance, risk management or regulatory reporting requirements) which together support the transition from exploratory to routine use.

5.6. Exploratory Cross-Context Juxtaposition

This section is an exploratory juxtaposition, not a test of differences between markets: the two assessments differ in respondent composition, elicitation format, product coverage (38 against 20 suites) and in the source of capability scores, and no statistical comparison is made.

Four patterns recur in both contexts: adoption barriers dominate over technological limits, with guideline and utilisation gaps more prevalent than R&D gaps; last-mile constraints are structurally similar, with cost, absent internal skills, integration difficulty and auditability concerns appearing consistently; asset context is a recurring enabler in both; and emissions monitoring constitutes a shared capability frontier.

The balance of barriers nonetheless differs. Awareness and cost were the barriers most frequently cited in the Türkiye responses, whereas the Europe/US evidence more often pointed to integration, procurement and audit-readiness. Because the two bodies of qualitative evidence were gathered from different respondent groups and analysed differently, this difference is suggestive and is not interpreted as a ranking of barriers across contexts. Europe/US shows higher operationalisation for green finance monitoring products, while the Turkish responses suggest stronger pilot-level usage but weaker institutional embedding. Regulatory incentives act as a strong differentiator: established disclosure regimes sustain the business case for integration, while less mature mandates weaken it. Table 3 summarises these dimensions. Because the Turkish sample is dominated by EO-sector perspectives and capability is carried over rather than locally elicited, comparisons should be read with caution. The Türkiye results therefore indicate how EO experts perceive financial-sector demand, recognition and use; they do not measure those quantities among financial institutions, and are treated as indicative rather than confirmatory of the Europe/US pattern.

Table 3. Dimensions of comparison between the Europe/US and Türkiye assessments.

Dimension	Europe and United States	Türkiye
Dominant gap type	Guideline and utilisation; R&D mainly for emissions	Same pattern
Key last-mile barriers	Cost of very-high-resolution (VHR) data, auditability, model integration, licensing	Awareness, cost, skills and capacity, workflow integration
Respondent base	Demand and capability scored by different communities	EO-sector and intermediary dominated (5% FM); supply-side bias
Most frequently described barriers	Procurement, integration and audit-readiness	Awareness and cost (keyword salience)
Utilisation maturity	Higher operationalisation for some green finance products; weaker for complex asset-level products	Stronger at pilot and project level, weaker institutional embedding
Regulatory context	Stronger disclosure regimes, established ESG reporting, mature vendor ecosystems	Less mature or inconsistent mandates; weaker sustained business case
Asset linkage	Recognised as critical; gaps visible in building inventory utilisation	Same dependency; integration barriers confine products to ad hoc use
Emissions monitoring	Consistent R&D gap; finance-grade capability not yet robust	Same; data fusion and validation partnerships needed
Capacity focus	Integration and compliance skills within FM teams	Translation, exposure and capacity building inside FM institutions

6. Discussion

6.1. Information Frictions Rather than Data Scarcity

Guideline and utilisation gaps outnumber R&D gaps in both contexts and all four domains. For the debate on the climate-related data gap the implication is specific: for most of the needs studied, the information financial institutions lack can already be produced, and the marginal return on effort lies in translation, integration and standardisation rather than in new observing capacity. Borges et al. (2023) reach a similar conclusion for national

risk-reduction systems; our results show that it also holds in finance and how it is distributed across product families. The guideline gaps in Sections 5.1 and 5.2 give empirical form to the problem Alonso et al. (2024) describe in linking environmental indicators to financially material metrics. That problem shows up as suppressed demand, not as dissatisfaction with the products on offer.

The framework in Section 2 offers an interpretation of the pattern. Where capability far exceeds expressed demand, as for accessibility metrics (UN11) and agricultural productivity indicators (UN18), the value of the information is not visible to the user (Rogers, 2003) and it is not treated as material. Where demand and capability align but use lags, as for building inventories (UN47) and land cover time series (UN38), institutions face the acquisition and processing costs that Grossman and Stiglitz (1980) place at the centre of information use, together with the missing facilitating conditions of Venkatesh et al. (2003): registries, pipelines and audit procedures. Absorptive capacity theory (Cohen & Levinthal, 1990) predicts that the two will occur together, since institutions with little geospatial knowledge both undervalue products and find them costly to deploy, and the Türkiye results are consistent with this. The remedies are not interchangeable. Whether the remedies indicated for guideline and utilisation gaps would raise adoption is not identified by this design. R&D funding will not close a guideline gap, and promoting products to meet an R&D gap risks overstating evidence that cannot be defended to an auditor or supervisor.

6.2. Asset-Location Data as an Important Complement

The most consistent cross-cutting finding is that satellite products become decision-ready only when joined to accurate asset registries, portfolio boundaries and internal risk models. This holds in both contexts and at all maturity levels, and it explains a result that would otherwise be puzzling: some of the most mature products in the portfolio, including land cover maps with capability of 4.0, show some of the largest utilisation gaps. Satellite data and asset-location data are complements, and the value of the first depends on the quality of the second. The finding agrees with Bressan et al. (2024), who show that ignoring the location of firms' physical assets leads to material underestimation of physical climate risk, and with climate stress-testing work that depends on mapping exposures to the counterparties that hold them (Battiston et al., 2017). The spatial finance literature has tended to treat asset location as an implementation detail (Caldecott et al., 2022). Our evidence suggests that it is often the dominant constraint, and that this constraint sits inside the financial institution rather than in the EO product.

6.3. Emissions Verification and Transition Risk

Emissions and carbon-intensity monitoring is the one area where the constraint is technological. It appears as an R&D gap in investment management (UN15) and green finance (UN26) and recurs in Türkiye, where high demand meets the same carried-over capability assessment. This matters for transition risk. Evidence that carbon emissions are priced in equity returns (Bolton & Kacperczyk, 2021) rests on reported emissions, and ESG ratings that incorporate them disagree (Berg et al., 2022). Independent satellite verification would narrow the scope for misreporting, but it cannot yet attribute observed emissions to individual firms or funded projects with defensible accuracy. Dogniaux et al. (2025) find substantial uncertainty in satellite-derived landfill methane emissions even at facility scale, and the reviews of Mehrdad and Du (2025) and Mohammadimanesh et al. (2025) show that point-source monitoring is still limited by resolution and detection thresholds for asset-level attribution. The high dispersion in expert capability scores (SD $\approx$ 1.0 for UN15) is informative in its own right. It suggests that judgements of capability depend on the use case assumed, since detecting large point sources at a single facility is a different

task from attributing carbon intensity across a portfolio. These readings are not exclusive: disagreement about readiness is likely to arise because respondents assume different use cases, and the R&D classification refers to the portfolio-level, asset-attributable monitoring that the financial need requires; the independent technical literature cited above points the same way. Until attribution improves, investors and lenders who rely on satellite data to support emissions claims face a verification gap that disclosure rules alone will not close.

6.4. Implications for Emerging Markets, Institutions and Supervisors

The Türkiye gap profile resembles that of Europe and the United States, but awareness and cost feature more prominently in the supply-side responses. This fits the argument of Manunta and Coulson (2024) that enabling conditions have to be addressed together: raising awareness without lowering cost, or lowering cost without building capacity, is unlikely to change use where all three bind at once. It also connects to the observation of Nakalembe et al. (2024) that EO development is largely externally driven. If product priorities reflect the interests of funders and developers more than local financial needs, guideline gaps in emerging markets are partly a product of how EO is developed, and closing them requires co-design as well as communication. The Türkiye responses suggest that TSRS and carbon border reporting may raise demand for environmental evidence faster than domestic institutions can absorb it. This is a hypothesis for testing with financial practitioners.

The implications below differ in the strength of the evidence behind them. The conclusions that most shortfalls are not technological and that emissions attribution is the main exception rest on the Europe/US expert scores and, for emissions, on the independent technical literature; the suggestions for institutions, providers and supervisors rest on respondents' reported reasons and on theory and are not tested interventions; and the Türkiye-specific implications rest on supply-side perceptions and carried-over capability scores and are exploratory.

For practice, the results suggest a sequenced response that differs by actor. Financial institutions may gain from improving their asset registries and adopting standard methods for joining EO outputs to holdings, because the value of other investments depends on asset linkage. EO providers may close guideline gaps by packaging existing products around specific financial decisions and publishing uncertainty and audit-trail information, and can reduce utilisation gaps through reference architectures and tiered pricing. Supervisors and standard setters can raise the expected benefit of adoption by clarifying when satellite-derived evidence is acceptable for disclosure and verification, giving institutions the assurance they need to move from pilots to routine use. Research funding is most clearly indicated for emissions attribution, where the constraint is technological.

6.5. Limitations

Several limitations qualify these findings. The Türkiye respondent pool is dominated by EO-sector professionals, with only two financial-sector participants, so findings reflect informed supply-side perspectives rather than direct practitioner experience; self-selection is likely to inflate perceived awareness and demand, and variability in how respondents interpreted product descriptions introduces measurement noise. The 780 evaluations are clustered within 39 respondents and are not independent. Capability was not re-elicited in Türkiye but carried over on the grounds set out in Section 4.6; suite-level capability does not vary by market, but capability as realised in a given country can be lower where validation reference data are sparse, so the Turkish R&D gaps are best read as lower bounds and the guideline gaps as upper bounds. Reducing the imported capability scores by 0.25 and 0.50 points lowers the number of guideline gaps and raises R&D gaps, as expected; the shift towards R&D and aligned products is shown in Supplementary Table S9, so readers can

judge how strongly the Türkiye conclusions depend on the common-capability assumption (Supplementary Table S9).

Participation from insurance stakeholders was limited in the Europe/US assessment, so those findings are directional. The scale is ordinal and means are a comparative summary rather than interval measurements (Jamieson, 2004), while demand was elicited at need level and the other criteria at pair level. Gap classification depends on a 0.5 threshold set by judgement and not derived empirically. Expert elicitation is subject to overconfidence and anchoring (Morgan, 2014; O'Hagan, 2019), which separating scoring roles mitigates but does not remove. Finally, the two contexts are not matched samples, differing in instrument coverage (38 suites against 20), respondent composition and elicitation format, so the comparison in Section 5.6 is a structured juxtaposition, not a controlled comparison, and the Türkiye findings characterise one emerging market rather than emerging markets generally.

7. Conclusions

This paper asked why financial institutions make limited use of satellite Earth observation for environmental risk assessment and reporting, and whether the shortfall reflects recognition, adoption or capability. A demand–use–capability framework, applied to 32 information needs and 38 product suites in Europe, the United States and Türkiye, was used to distinguish guideline, utilisation and R&D gaps. Because 37 of the 39 Türkiye respondents were EO experts and providers, the Türkiye findings describe how the supply side perceives financial institutions' demand and use, not the experience of financial institutions themselves. Confirming them requires a survey of financial practitioners.

Guideline and utilisation gaps predominate in both settings. The main barriers are awareness, translation into financial terms, cost, integration and audit-readiness; sensor capability is rarely the limiting factor. R&D gaps are concentrated in emissions and carbon-intensity monitoring, where demand is consistently high but asset-level attribution remains beyond current capability, which leaves transition-risk assessment dependent on self-reported data. Asset-location data are an important complement in both contexts, and in the Türkiye responses (which reflect EO-sector perceptions of the financial market) awareness and cost were the most frequently cited barriers. For financial institutions and supervisors, the climate-related data gap is therefore to a large extent an organisational gap. Effort and funding may be more effective if they follow whichever gap type binds in a given application, since the remedies for the three are not interchangeable.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/jrfm19110938/s1, Table S1: Summary of geospatial user needs in the financial-management sector, grouped by thematic categories; Table S2: List of 38 consolidated EO products; Table S3: Investment Management user needs demand scores with the capability and utilisation scores for the associated EO products; Table S4: Green Finance user needs demand scores with the capability and utilisation scores for the associated EO products; Table S5: Risk Analysis user needs demand scores with the capability and utilisation scores for the associated EO products; Table S6: Insurance Management user needs demand scores with the capability and utilisation scores for the associated EO products; Table S7: Sensitivity of the gap classification to the threshold; Table S8: Ordinal robustness of the gap classification; Table S9: Sensitivity of the Türkiye gap classification to reductions in the imported capability scores. The expert scores underlying the analysis are given in Tables S3–S6.

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Informed Consent Statement: Informed consent was waived because participation was voluntary and anonymous, and no personally identifiable information was collected. Completion of the questionnaire was taken as implied consent.

Data Availability Statement: The original contributions presented in this study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author(s).

Conflicts of Interest: Authors Enes Hisam and Dhritiraj Sengupta are employed by GMV. Author Rahman Momeni is employed by HE Space. The remaining author (Dursun Zafer Seker) declares no competing interests. All authors confirm that the research was conducted in the absence of any other commercial or financial relationships that could be construed as a potential conflict of interest, and that the aforementioned companies had no influence on the study design, data analysis, or manuscript preparation.

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