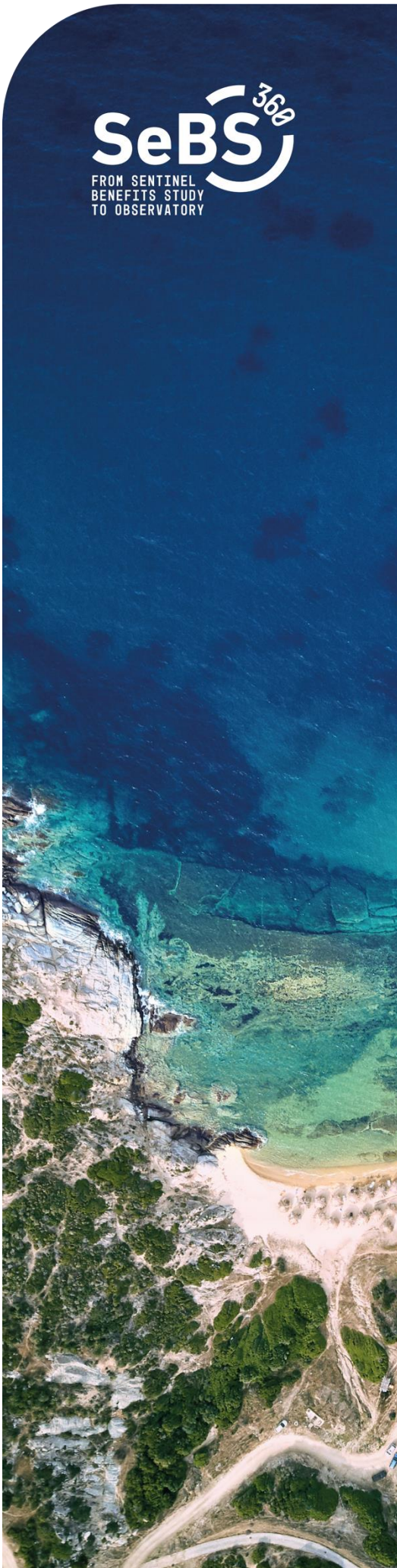
Powerline Monitoring in Colombia

Case Study

October 2026



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Setting the scene

Don Hernán had farmed the same slope above the Magdalena valley for forty years, and he knew the ground the way he knew his own hands. He knew where the soil crept after the heavy rains of the wet season, where the little spring appeared and disappeared between the coffee, and where, three ridges over, the tall steel towers carried the power lines down towards Bogotá.



What he did not know, until the engineers arrived, was that one of those towers was in trouble.

The engineers were polite and unhurried. They unrolled a map on the bonnet of their pickup, and it was not like any map he had seen. It was covered in coloured dots: most of them green, a few of them orange, and one small angry cluster of red, sitting right at the foot of the tower nearest the river. The young woman explained that the colours came from a radar on a satellite, flying some seven hundred kilometres over their heads, that passed over this exact valley every few days and could measure the ground moving by amounts smaller than the width of his thumbnail.

“The river is eating the bank under the tower,” she said, tracing the red cluster with her finger. “Slowly. You would not see it for years. But the satellite has been watching since before you noticed the spring move, and it can see that this corner has been sinking the whole time.”

Don Hernán thought about the lights in the villages down the valley, the pumps, the clinic in the town that needed its refrigerators kept cold. He thought about the night, years ago, when a tower further north had come down in a slide and half the region had gone dark for two days.

“So, you will fix it?” he asked.

"We will fix it," she said, "before it breaks. That is the whole point. The satellite does not tell us what to do. It tells us *where to look*. The looking, and the deciding, and the fixing, that is still our job. But now we are looking in the right place."

She rolled up the map. Above them, unseen and unheard, the radar passed over the ridge again, and the ground gave up another millimetre of its secret.

Whilst the characters in this story are entirely fictional, the situation is inspired by real events based on our knowledge gained through the case interviews.

Executive summary

This case study examines how **ground-deformation information** derived from the European Copernicus **Sentinel-1** mission supports the management of **high-voltage electricity** transmission infrastructure in Colombia. The country's transmission corridors cross mountainous, rainfall-exposed and seismically active terrain, where slow ground movement, **erosion and landslides can threaten tower foundations and line integrity**. Because these assets extend across thousands of kilometres, field inspection alone cannot provide a continuous view of changing ground conditions. Sentinel-1 helps address this gap through wide-area, repeatable and all-weather observations.

The value chain begins with Detektia, a Spanish service provider that processes Sentinel-1 radar data using satellite radar interferometry (InSAR) to **produce ground-motion information** (Tier 1). GeoAndina, a Colombian geotechnical engineering group, **combines these outputs with local geological and engineering knowledge to develop recommendations** (Tier 2). Grupo Energía Bogotá and its transmission company Enlaza use those recommendations to **guide inspection, maintenance and intervention decisions** (Tier 3). Citizens and economic activities that depend on reliable electricity transmission form Tier 4.

The central finding is that **Sentinel-1 does not replace engineering judgement**; it makes that judgement more focused, timely and evidence-based. It does not predict failure or prescribe an intervention. Instead, it **establishes a historical baseline**, shows where deformation is accumulating and directs inspection and engineering resources towards locations that warrant closer attention. The value comes from the chain through which radar observations are processed, interpreted, verified and translated into action.

The benefits are assessed across six dimensions. At the service-provider level, using free Sentinel-1 data in place of commercial radar data avoids an estimated **€320,000 per year** in data-acquisition costs for the monitored corridors, and about **€500,000** cumulatively to date. Downstream, InSAR prioritisation is estimated **to avoid €5,000–10,000 a year in field inspections** and to support an indicative **saving of approximately €200,000 per major corridor-planning exercise**, while the probability-weighted benefit of averting terrain-driven failures is estimated at roughly €24,000–240,000 a year, against a single-event exposure of several million euros. Taken together, the annual Tier 1 and Tier 3 estimates indicate an **illustrative combined range of approximately €350,000–570,000 per year**. This range should be interpreted cautiously because its components use different counterfactuals and evidence bases; the corridor-planning estimate is reported separately and is not annualised or included in the combined range.

Beyond the economic benefits, the case supports innovation and entrepreneurship by enabling Detektia's Sentinel-based business and GeoAndina's use of InSAR in more preventive infrastructure management. Societal benefits arise indirectly through reduced risk of electricity-

supply disruption. Regulatory benefits relate mainly to avoiding regulated unavailability and unsupplied-energy charges. **Environmental** benefits are limited and remain **potential** rather than demonstrated for the monitored corridors. One possible pathway is that avoiding a **terrain-driven line failure** could also prevent **wildfire ignition** and its wider impacts on ecosystems, health and air quality.



The Sentinel Data

Copernicus Sentinel-1 provides free-of-charge, all-weather, day-and-night C-band radar imagery over Colombia's mountainous transmission corridors, with a revisit of roughly 6–12 days and an archive reaching back to 2014.



Tier 1: Detektia (Service Provider)

Sentinel-1 InSAR ground-deformation monitoring services. Avoided commercial-radar-data cost (~€320,000/year), an enabled university spin-off sustaining five skilled jobs, and award-recognised algorithm development.



Tier 2: GeoAndina (Primary User)

Interpretation of InSAR deformation data into engineering decisions across a 2,500–3,000 km network narrowed to ten critical sectors. Reduced field-inspection effort, leaner corridor design through lower uncertainty, and an efficient shift in practice.



Tier 3: Enlaza / Grupo Energía Bogotá (Secondary User)

Protection of asset value through targeted, preventive intervention on terrain-driven risk. Probability-weighted avoided failure loss (~€24,000–240,000/year) against a single-event exposure in the tens of millions, avoidance of regulated CREG penalties, and safeguarded public infrastructure.



Tier 4: Citizens and Society

Reliable electricity for the ~96% of Colombians served by the national grid. Avoided disruption to households, public services and economic activity, and, indirectly, reduced wildfire-ignition risk from terrain-driven line failures.

1 Introduction and scope

1.1 The context of this study

The analysis of the case study '**Powerline Monitoring in Colombia**' is carried out in the context of the Sentinel Benefits Observatory (SeBS360), an activity of the European Space Agency that builds on and extends the long-running Sentinel Benefits Study (SeBS). SeBS has produced a foundational methodology[1] and a portfolio of case studies documenting how Earth Observation (EO) services based on Copernicus Sentinel data deliver value across the value chain to users, society, and the wider economy. The SeBS360 project continues the case-study work and adds a programme-level synthesis layer aimed at extracting sectoral synopsis-type insights found in the benefit patterns the Sentinels generate across sectors and geographies.

The Sentinels form a central part of the European Union's Copernicus Programme, providing space-based observations on a full, free, and open basis. Sentinel data are thus a key component of the Copernicus Services, and a crucial source used by companies to deliver products and services helping different users across the globe. Data from the Sentinel missions, together with other relevant data sources and complementary information, support a wide range of application areas, including agriculture, forestry, climate monitoring, environmental protection, disaster risk management, and natural resource management. Sentinel data therefore constitutes a key input for the development of downstream products and services delivered by companies and organisations to users in Europe and beyond.

1.2 What is the case all about?

Infrastructure exposed to unstable ground conditions requires monitoring approaches that can detect change over time and support timely engineering decisions. This is especially important where deformation develops gradually and affects assets distributed across long corridors rather than a single fixed site. In Colombia, this challenge is particularly important because many infrastructure networks cross mountainous and unstable terrain, where ground movement can create risks for assets that are difficult to monitor through site visits alone.

In this context, the present case examines how satellite-based deformation monitoring is used in Colombia to support infrastructure risk management in power transmission networks. The case focuses on three core actors: Detektia, a Spanish service provider specialising **in InSAR-based infrastructure monitoring** which provides the Artificial Intelligence (AI)- and Machine Learning (ML)-supported satellite-based deformation monitoring capability; GeoAndina, a

[1] The previous Sentinel Benefits Study project produced a foundational methodology for the assessment of the impact and benefits the Sentinels have on various aspects of industry, science and society. The methodology is available on the following link: https://sebs360.eu/wp-content/uploads/2026/03/SeBS-Methodology-2024.pdf

Colombian geotechnical engineering group which uses and interprets the resulting information in an engineering context; and Grupo Energía Bogotá, a **Colombian energy group**, through its transmission company Enlaza, which is the asset owner that acts on the resulting recommendations. The case therefore focuses not only on the technical use of **Sentinel-1** data, but also on how that information is translated into practical risk screening, **prioritisation**, and more **preventive infrastructure management**. The case also illustrates how better information can help focus inspections and maintenance across a large transmission network, supporting more targeted intervention and contributing to the reliability of electricity supply.

1.3 More about the study

Each case study developed under SeBS360 focuses on products and services that use data coming from Sentinel satellites and examines how the resulting value is generated across the value chain. The analysis starts from the direct use of Sentinel-derived information by the relevant users in the case and then follows the subsequent links in the value chain in order to understand how benefits extend beyond the immediate user to other organisations, asset owners, and ultimately citizens and society.

In this process, the main aim is to understand and demonstrate the value generated through satellite-based Earth Observation, and in particular through the use of data from the Copernicus Sentinel missions. Each case study therefore seeks to trace the link between the use of Sentinel data and the benefits that arise from that use. These benefits may include, among others, improved operational efficiency, better-informed decision-making, reduced uncertainty, economic gains, increased safety, strengthened resilience, and wider societal value.

The evidence generated through these case studies can be useful to different groups. For decision-makers, a portfolio of concrete and well-documented cases helps demonstrate where and how Sentinel data creates practical value, thereby supporting future investment and policy decisions. For users, such case studies provide clearer evidence of what Earth-Observation-based services can contribute in comparable operational settings. For service providers, robust evidence on the benefits associated with Sentinel-enabled services can strengthen communication, market positioning, and the broader promotion of such solutions.

1.4 Acknowledgements

Producing this case study report would have been impossible without the insights and kind assistance of key stakeholders, who helped us navigate the technical, operational and commercial aspects of the case. We would like to extend particular thanks to the teams at Detektia and at GeoAndina for the time and candour they brought to the interviews on which this analysis rests. In particular:

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2 Powerline Monitoring in Colombia Overview

2.1 Colombia's electricity grid

Colombia's electricity supply is delivered through the **Sistema Interconectado Nacional (SIN)**, the national interconnected system that links the country's main generation centres to its demand centres, including Bogotá, Medellín, Cali, Barranquilla and the other main cities. As of 2025, the SIN extends to some **30,205 km** of transmission lines across the national and regional networks, the higher-voltage tiers forming the backbone of the **Sistema de Transmisión Nacional (STN)**, which operates at **220 kV** and above and comprises **133 substations**, of which 23 operate at 500 kV.[2] Real-time operation of the system, together with administration of the wholesale energy market, is the responsibility of XM, the independent system operator, which manages a grid whose installed capacity is projected to rise from 21.5 GW to 37.7 GW by 2033.[3] The transmission layer is dominated by Interconexión Eléctrica S.A. (ISA) and its subsidiary INTERCOLOMBIA, which owns the whole of the legacy 500 kV network and the majority of the existing high-voltage system; new STN expansion, however, is awarded competitively through public reverse-auction tenders, with the assets belonging to the successful investor rather than to a single dominant owner.

Sector roles are institutionally separated. Policy is set by the Ministerio de Minas y Energía (MME); long-term planning, including the mandatory Transmission Expansion Plans, is the remit of the Unidad de Planeación Minero-Energética (UPME); economic regulation, including tariffs and the rules governing supply quality, falls to the Comisión de Regulación de Energía y Gas (CREG); and real-time dispatch is carried out by the National Dispatch Centre (CND), operated by XM. This separation of planning, regulation and operation, established under Laws 142 and 143 of 1994, is the framework within which transmission assets such as those examined in this case are built, maintained and remunerated.[2]

Hydropower dominates the generation mix, supplying around 58% of electricity generated in 2024, with natural gas (around 19%) and coal (around 12%) making up most of the balance. [4] That reliance on hydroelectricity leaves the system exposed to hydrological variability: 2024 was an El Niño year, in which reduced rainfall forced greater recourse to thermal generation, and droughts have historically translated directly into supply stress.[5]

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[2] Sáenz Tovar, G., & Vega-Araújo, J. (2026). Electricity transmission in Colombia: overview 2025. Stockholm Environment Institute. https://doi.org/10.51414/sei2026.021 (figures sourced therein to XM, UPME and PARATEC).
[3] Kelly, A., & Ramirez, L. (2024). XM Control Room of the Future Roadmap: A Vision for the Future of Transmission Operations in Colombia. National Renewable Energy Laboratory / EPRI / G-PST Consortium (capacity figure sourced therein to XM, 2023). https://globalpst.org/wp-content/uploads/XM-Control-Room-of-the-Future-Gaps-and-Actions_public_V3_Ingles.pdf
[4] IEA (2024), Colombia: Electricity, generation by source 2024. https://www.iea.org/countries/colombia/electricity
[5] Global Energy Monitor, Energy profile: Colombia. https://www.gem.wiki/Energy_profile:_Colombia

The network is expanding to meet rising demand and to connect a large pipeline of new renewable capacity, and it is doing so under strain. Available transmission capacity has fallen below 5% in several regions, and roughly 90% of substations are projected to exhaust their short-circuit interruption capacity between 2024 and 2029, which directly constrains the integration of new generation. UPME's Master Plan for the Modernisation and Expansion of the transmission infrastructure sets out a portfolio of 98 strategic works, of which at least 44 would need to be delivered to overcome the operational constraints projected to 2034; project execution, however, is itself a structural weakness, with 55% of the transmission projects currently underway delayed, some by a decade or more.[2] The 2.4 GW Hidroituango hydroelectric project, whose completion was delayed by landslides and flooding of its powerhouse, is an illustration of how directly terrain instability bears on the country's electricity infrastructure.

That exposure is not confined to generation. Much of the transmission network crosses mountainous, high-rainfall and seismically active terrain, where ground movement threatens tower foundations and line integrity. It is this vulnerability – the susceptibility of transmission assets to terrain-driven failure – that the remainder of this section examines, and that the monitoring service assessed in this case is intended to address.

2.2 Ground instability and infrastructure exposure in Colombia

Colombia's physical geography makes ground instability a recurring infrastructure challenge rather than an occasional local problem. The country combines steep Andean terrain, heavy rainfall, complex geology, and widespread exposure to multiple natural hazards. In practice, this means that landslides are not isolated anomalies but part of the wider risk landscape within which infrastructure must be planned, built, and maintained. Hazards such as slope failure, creeping ground movement, and rainfall-triggered instability can develop progressively, affect access routes and supporting corridors, and generate operational consequences well beyond the precise point at which movement first becomes visible.

The relevance of landslides to infrastructure is heightened by the concentration of population and economic activity in mountainous terrain. The Andean region is the most populous region of the country,[6] where settlements, transport links, utilities and engineering assets occupy steep and fragmented landscapes. Engineering-geology studies have shown that risks to life and infrastructure from landslides have increased over time, particularly in urban and developed areas within these mountainous regions.[7] This exposure is compounded by climate: Colombia is among the wettest countries in the world, with a long-term average of around 3,240 mm of

[6] Castillo, A., Gomes, V., Ossa, H. et al. (2025). An overview of the mtDNA diversity across the Colombian Andean region. Forensic Science International: Genetics, 78, 103288 https://doi.org/10.1016/j.fsigen.2025.103288
[7] Ojeda, J., & Donnelly, L. (2006). Landslides in Colombia and their impact on towns and cities. IAEG2006, Paper 112, Geological Society of London. https://media.geolsoc.org.uk/iaeg2006/PAPERS/IAEG_112.PDF

precipitation per year – almost three times the world average – and far higher totals in parts of the Andes and the Pacific.[8] Heavy and prolonged rainfall is the most frequent trigger of slope failure – responsible for 92% of the landslides registered in Colombia between 1900 and 2018 – and the country's position along the Pacific Ring of Fire adds significant seismicity as a further driver of instability.[9] The infrastructure challenge is therefore not simply whether a given asset is well designed at one fixed point, but whether the ground conditions along the wider corridor remain stable enough for the asset to continue operating safely and reliably.

This broader context is especially relevant for long, distributed assets such as powerline corridors. Unlike a single facility concentrated on one site, powerline infrastructure passes through multiple terrain types, slope conditions and drainage environments, which means exposure can vary significantly from one segment to another.

The scale of this exposure is not hypothetical. The 2010–2011 La Niña phenomenon caused tens of thousands of landslides across broad regions of the country and severely affected infrastructure, illustrating how a single prolonged wet period can translate directly into widespread terrain instability and damage to transport, utility and energy assets.[10]

The historical record confirms the scale. A national compilation covering 1900–2018 registers 30,730 landslides, 34,198 fatalities and direct losses of USD 654 million, with 92.5% of rainfall-triggered landslides concentrated in the Andean region, on 33% of the national land mass.[11] Occurrence is closely coupled to climate variability: analysis of 4,976 landslides in the Andean region between 1981 and 2022 shows activity aligned with the bimodal rainfall cycle and markedly more frequent landslides in La Niña years, alongside an increasing trend in occurrence.[12] In terms of exposure, the Servicio Geológico Colombiano (SGC)'s national hazard zonation places 19% of national territory in high or very high landslide hazard, with the Andean region combining 24.5% in high and 53.7% in medium hazard,[13] and the national disaster-risk agency – the Unidad Nacional para la Gestión del Riesgo de Desastres (UNGRD) – estimates, by

[8] World Bank / FAO, Average precipitation in depth (mm per year) – Colombia (indicator AG.LND.PRCP.MM, long-term average). https://data.worldbank.org/indicator/AG.LND.PRCP.MM?locations=CO
[9] Aristizábal, E., & Sánchez, O. (2020). Spatial and temporal patterns and the socioeconomic impacts of landslides in the tropical and mountainous Colombian Andes. https://doi.org/10.1111/disa.12391
[10] GeoEngineer (2010). Series of landslides claim 36 lives in Colombia. https://www.geoengineer.org/news/series-of-landslides-claim-36-lives-in-colombia
[11] Aristizábal, E., & Sánchez, O. (2020). Spatial and temporal patterns and the socioeconomic impacts of landslides in the tropical and mountainous Colombian Andes. https://doi.org/10.1111/disa.12391
[12] Vega, J., Barco, J., & Hidalgo, C. (2024). Space-time analysis of the relationship between landslides occurrence, rainfall variability and ENSO in the Tropical Andean Mountain region in Colombia. Landslides. https://doi.org/10.1007/s10346-024-02225-9
[13] Servicio Geológico Colombiano (2017). Las amenazas por movimientos en masa de Colombia: una visión a escala 1:100.000. Primera edición. Bogotá: SGC. https://libros.sgc.gov.co/index.php/editorial/catalog/book/45

crossing the hazard map with the 2018 census, that more than 80% of the population is exposed to high or very high hazard.[14]



Figure 1 Flooding in Colombia during the 2010 La Niña event. Note. From "En Fotos: 'La Niña' inunda Colombia," by BBC News Mundo, November 18, 2010. Copyright 2010 by BBC News Mundo or the credited image rightsholder.

2.3 Monitoring challenges in linear infrastructure

Linear infrastructure is inherently more difficult to monitor than assets concentrated on a single site because it extends across long corridors and therefore passes through changing terrain, drainage conditions, geological formations and slope profiles. Risk is distributed unevenly: one section of a corridor may remain stable while another becomes vulnerable to slow deformation, erosion or slope failure. The operational challenge is therefore not only to observe the asset itself, but also to understand how local ground conditions vary along its full extent, and where instability may begin to threaten performance, access or safety.

This challenge is particularly acute in landslide-prone settings because the consequences are often highly localised in origin but system-wide in effect. Hazard-screening guidance for Colombia notes that landslides can damage infrastructure such as water and gas pipelines and can also affect electricity infrastructure, including transmission towers that may be struck by landslides or built on moving ground.[15] This matters for powerline monitoring because

[14] UNGRD (2020). Riesgo por movimientos en masa en Colombia. Unidad Nacional para la Gestión del Riesgo de Desastres, 19 August 2020. https://portal.gestiondelriesgo.gov.co/Paginas/Noticias/2020/Riesgo-por-movimientos-en-masa-en-Colombia.aspx

[15] ThinkHazard (GFDRR), Colombia landslide hazard guidance. https://thinkhazard.org/en/report/57-colombia/LS

transmission assets may appear structurally sound while the ground supporting them is gradually becoming less stable. The monitoring problem is therefore not limited to detecting visible structural failure; it also involves identifying the early ground movements that can precede more serious asset instability, service disruption, or more costly maintenance.

Powerline corridors illustrate these challenges clearly because they combine long spatial extent with repeated exposure points such as towers, foundations, and access routes. Each tower may sit in a different local geotechnical context, and the surrounding slopes or drainage conditions can change substantially along the route. Monitoring cannot rely only on isolated field checks, or on the assumption that conditions at one tower are representative of the next. What is needed instead is a way to screen the broader corridor, identify sections showing possible deformation, and then focus engineering attention where the signal indicates a higher likelihood of instability. This is the broader operational logic that makes wide-area, repeatable Earth Observation relevant before any case-specific service design is considered.

2.4 From repeated observation to operational decision-support

Ground-movement monitoring in infrastructure settings requires information that conventional local inspection alone cannot easily provide. It must cover broad areas, be repeatable over time, and allow engineers to distinguish isolated anomalies from persistent deformation trends, because instability often develops progressively rather than as a single sudden event. The operational challenge is not only to identify whether the ground has moved, but to understand whether movement is continuing, accelerating, stabilising, or spreading to adjacent sections of the corridor.

Repeated Earth Observation is valuable in this respect because it enables the same area to be observed systematically over time, building a temporal record that supports trend-based interpretation rather than a one-off observation. For corridor-based infrastructure this changes how information can be used operationally: instead of relying on isolated site visits or point measurements, engineers can work with historical baselines, periodic updates, and spatially consistent information across a wide footprint, screening the corridor first and then concentrating attention on the sections where deformation signals appear persistent or unusual. The central challenge in such settings is rarely an absolute lack of data; it is the difficulty of knowing where to direct limited engineering and inspection resources across a long and spatially variable corridor. This reframes maintenance and risk management: rather than applying periodic checks uniformly across the asset, resources can be directed towards the locations where emerging instability is more likely to affect performance, safety or service continuity.

In powerline corridors, a deformation process affecting one section can trigger repeated inspections, maintenance delays, restricted access, or heightened concern around asset

reliability, even before any failure occurs. Monitoring here is as much about managing uncertainty as measuring movement. The operative question is not whether the ground has moved but whether the movement warrants closer scrutiny – field verification, mitigation planning, or a shift in maintenance priorities. In the Colombian transmission context this is sharpened by physical geography – corridors that run for thousands of kilometres across mountainous, intensely rainfall-exposed and seismically active terrain – and by the fact that the cost of a terrain-driven interruption is borne well beyond the line itself, by an electricity system already operating close to its limits. The technique applied in this case, satellite radar interferometry (InSAR), and the characteristics of the Sentinel-1 data it relies on, are examined in detail in Section 3.

This is what makes the case analytically relevant in SeBS360 terms: it shows how freely available Sentinel data can support a chain of practical value in which wider-area situational awareness improves the efficiency and focus of professional decision-making.

2.4.1 Collecting the necessary data

Collecting the necessary data in this case is not simply a matter of obtaining imagery; it is a matter of assembling a monitoring dataset that is usable for engineering screening. For corridor-based infrastructure, the data must be capable of showing where deformation is occurring, how widespread it is, and whether the observed signal is concentrated around specific supports, slopes or adjacent terrain. The dataset therefore needs to support spatial comparison along the corridor, so that areas of relative stability can be distinguished from sections that deserve closer attention. In practice, the requirement is for a dataset that can be interpreted as a screening layer for prioritisation, rather than as a standalone engineering diagnosis.

A second requirement is temporal breadth. A useful dataset has to show how conditions have evolved over time, not only where they stand today. This makes historical baseline information a core part of the data requirement, because isolated observations are often insufficient for deciding whether a signal is normal background behaviour or an indication of a more relevant change. A dataset that combines archive observations with regular updates is therefore much more useful for engineering triage than a dataset limited to recent snapshots.

The data also need to be consistent enough for comparison across acquisition dates, which means the monitoring approach must rely on repeated observations that can be processed into a stable time series. For the primary user, comparability matters as much as coverage.

Finally, the data should be usable alongside other engineering information rather than in isolation: deformation signals become more useful when they can be read together with terrain conditions, drainage patterns, slope behaviour, site history and other operational knowledge.

The necessary data in this case are therefore best understood as one part of a wider evidence base that supports professional interpretation, not as a self-sufficient answer on their own.

3 The use of Sentinel data

3.1 How can satellites help with ground instability and infrastructure monitoring?

Remote-sensing techniques are increasingly used to provide timely and accurate data on aspects of geotechnical engineering and infrastructure health. The combination of satellite imagery with meteorological data, geological modelling and advanced algorithms supports the continuous monitoring of terrain and the identification of deformation patterns relevant to infrastructure. This enables the detection and monitoring of creeping ground movement, subsidence and landslides that may threaten distributed assets such as powerlines. The ability of satellites to gather millimetric deformation data over large areas, with a high revisit frequency, is leveraged to shift infrastructure management from a reactive towards a more preventive footing.

There are two main classes of Earth-observation satellites. The first carry passive sensors that detect the Sun's energy as it is reflected from the Earth's surface. These optical satellites essentially produce photographs, but they are severely affected by cloud cover and can only observe during daytime. The second carry active sensors that emit their own energy to illuminate the scene they observe, sending a pulse of energy to the ground and recording the radiation backscattered from the surface. Satellites carrying Synthetic Aperture Radar (SAR) sensors are unaffected by cloud cover or weather conditions and can operate day and night. Sentinel-1 is especially relevant in this context because it is a C-band SAR mission designed to provide systematic, repeatable observations well suited to deformation monitoring over time.

In the context of ground instability in Colombia, a country characterised by intense rainfall regimes and persistent cloud cover, optical satellites often fall short because observation conditions are not always reliable. SAR satellites overcome this barrier by providing data independently of daylight and most weather conditions. For deformation monitoring, this consistency is especially important because it allows the same area to be observed repeatedly through time rather than only intermittently.

To measure ground movement, engineers use a technique called SAR interferometry (InSAR). By comparing multiple radar images of the same location taken at different times, InSAR measures phase differences in the returning radar signal, making it possible to detect millimetre-scale surface displacement across repeated acquisitions.[16] The value of Sentinel-1 is therefore not only that it observes broad areas, but that it supports the creation of a consistent temporal

[16] Wasowski, J., & Bovenga, F. (2015). Remote sensing of landslide motion with emphasis on satellite multitemporal interferometry applications: an overview. In T. Davies (ed.), *Landslide Hazards, Risks and Disasters*, pp. 345–403. Elsevier. https://doi.org/10.1016/B978-0-12-396452-6.00011-2

record that can reveal subtle and cumulative ground motion before more visible instability appears.

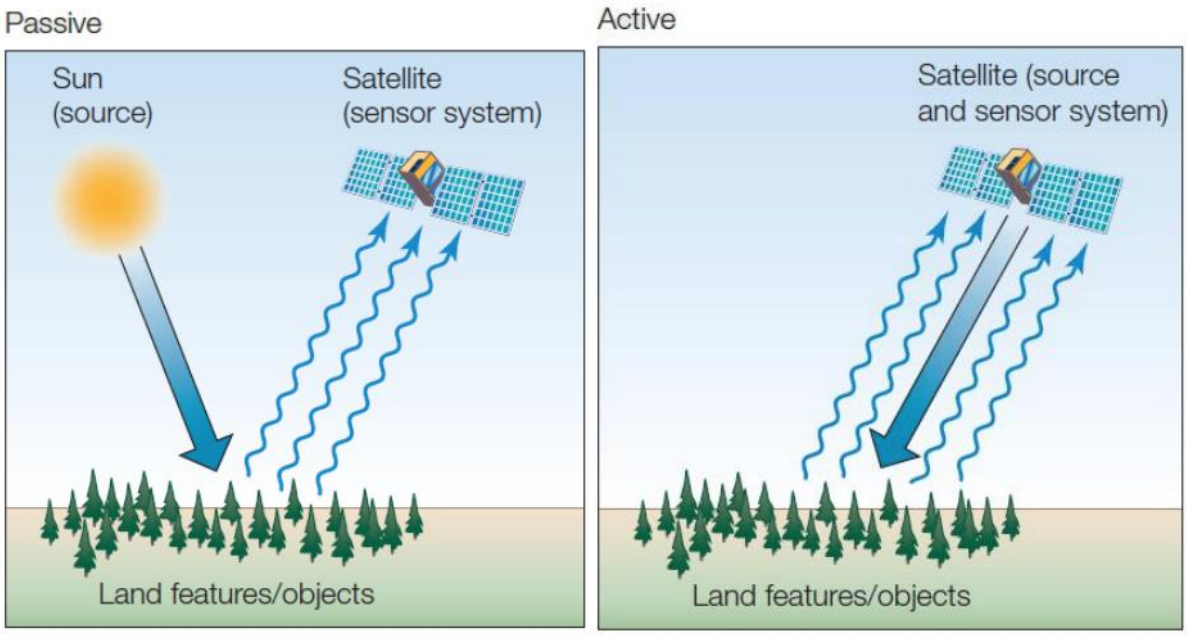


Figure 2 Passive (optical) versus active (radar) Earth observation (ESA EO Science for Society training materials, 2025)

Sentinel-1 is especially relevant in this context because it is a Synthetic Aperture Radar (SAR) mission operating in the C-band (Figure 3), and as other SAR EO systems, can provide systematic and repeatable observations independently of cloud cover and daylight.

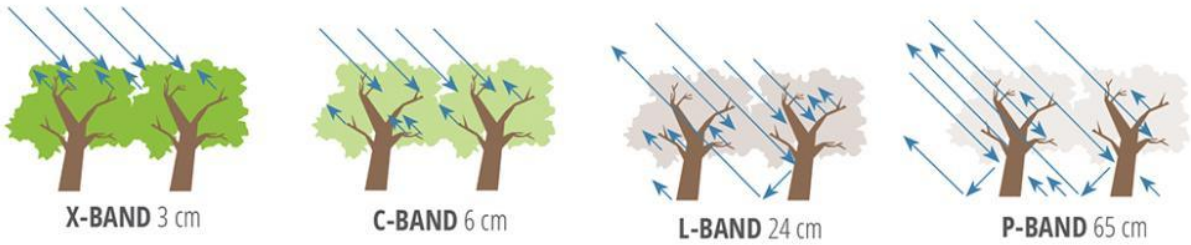


Figure 3 Sensitivity of SAR measurements to forest structure and penetration into the canopy at different wavelengths used for airborne or spaceborne remote sensing observations of the land surface. Credit: NASA SAR Handbook.

For monitoring applications in cloudy equatorial regions, this consistency is particularly important and is one of the most valuable characteristics of the data, as it allows the creation of a much more reliable temporal record than can typically be achieved with optical imagery alone. Because radar backscatter is sensitive to the structural properties of the objects on Earth's surface, repeated SAR observations can also be used to detect structural changes in forest cover through time.

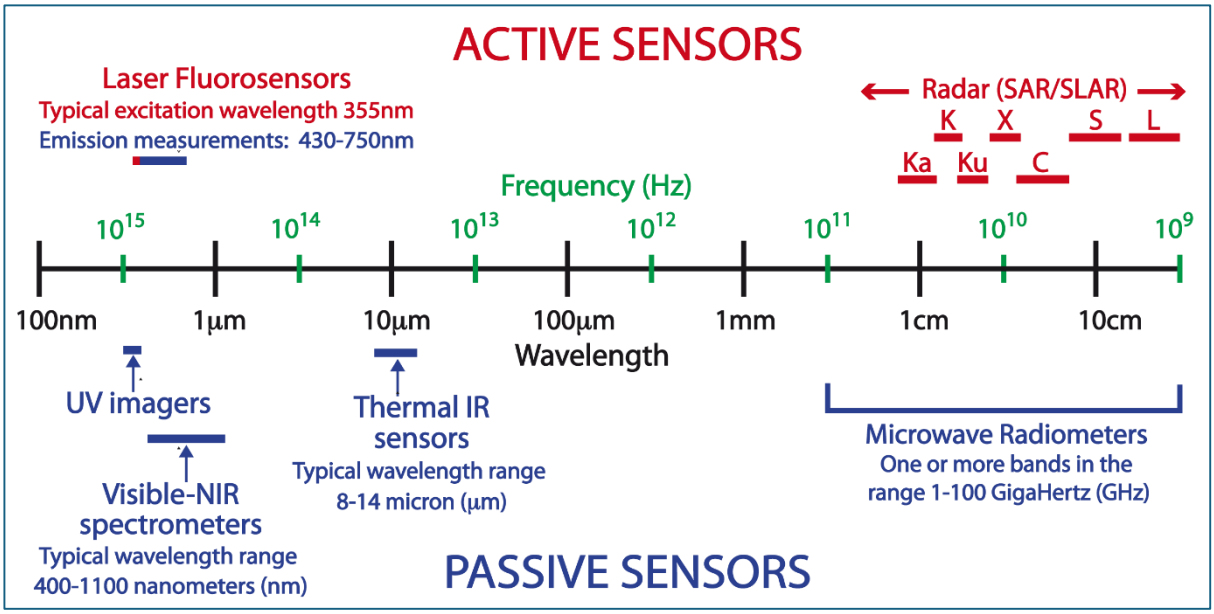


Figure 4 Schematic representation of the segments of the electro-magnetic spectrum in which each EO sensors operate

As seen in Figures 2 and 4, active and passive sensors emit/collect electromagnetic signals of different wavelengths. In practice, different materials on the Earth's surface reflect electromagnetic waves in a different manner. These reflectance differences allow EO satellites to distinguish between grasslands, water surfaces, forests, and buildings

3.1.1 Advantages

The most important advantages of satellite-based ground monitoring in infrastructure applications include:

- **All-weather observation.** The capability to acquire data regardless of cloud cover or weather conditions, when using active SAR sensors, provides a robust and continuous stream of information in tropical or mountainous environments.
- **Historical traceability.** Sentinel data provide a deep historical archive. Engineers can analyse the historical behaviour of sufficiently coherent terrain points over several years, providing an objective baseline to determine whether a recent movement is a new anomaly or part of a longer-term trend.
- **Spatial continuity.** Unlike conventional topography, which relies on discrete, fixed ground-control points that might miss an instability zone entirely, satellite images offer spatially continuous coverage across long infrastructure corridors.
- **Objective evidence.** Satellite data generate consistent, relatively objective information that does not depend on individual, on-site interpretation. This provides impartial evidence that can support engineering decisions and improve the credibility of technical recommendations.

3.1.2 Limitations

When compared to alternatives such as on-site geotechnical instrumentation, satellite-based deformation mapping presents the following limitations:

- **Resolution and scatterer limitations.** Spatial resolution may not be high enough to detect movement on very small, isolated assets unless they act as strong persistent scatterers, such as metal pylons or bare rock.
- **Vegetation decorrelation.** While radar penetrates clouds, dense vegetation can cause the radar signal to scatter unpredictably over time. In highly vegetated Colombian corridors, advanced algorithmic approaches are required to isolate true ground movement from canopy noise.
- **Terrain geometry.** Steep slopes introduce geometric distortions – foreshortening, layover and radar shadow – so some slopes are visible from only one viewing direction; characterising movement fully requires complementary geometries that are not available everywhere (see Section 6.3).
- **Quality filtering in vegetated terrain.** In rural vegetated corridors, a strict quality criterion must be applied to retain only reliable measurement points. In a Colombian power-line monitoring project, GeoAndina retained only measurement points with a quality (model-fit) value above 0.43 on a 0–1 scale, which reduced the number of valid analysis points but improved the reliability of the retained displacement trends.[17]
- **Data complexity.** Raw InSAR data are complex and heavy. They cannot be used directly by most civil engineers without significant processing, requiring specialised intermediaries to translate phase differences into usable deformation metrics. This is precisely the boundary at which the Detektia–GeoAndina relationship is organised.

In some power-transmission settings, metallic towers can provide strong radar reflectors and vegetation may be controlled around tower sites, partially mitigating vegetation and scatterer limitations. However, detectability remains site-specific, and slow deformation affecting lattice-steel towers may still be difficult to measure.

InSAR measurements are one-dimensional: the radar measures movement only along its line of sight to each point, rather than true three-dimensional ground displacement. To resolve the vertical and horizontal components of terrain movement, measurements from both ascending and descending satellite passes must be combined, since each geometry views the ground from a different direction. Where both geometries are available, this decomposition allows the millimetric precision characteristic of the technique. Where only one viewing geometry is available over a given area, however, the magnitude of displacement cannot be resolved as

[17] Salazar, H. A., & Restrepo, V. H. (2020). Remote sensing monitoring applications for landslides in infrastructure projects in Colombia. *SCG-XIII International Symposium on Landslides*, Cartagena, Colombia, 15–19 June 2020.https://www.issmge.org/uploads/publications/105/106/ISL2020-145.pdf

precisely, although the data still reliably identify which zones are accumulating deformation and therefore warrant closer attention. In the Colombian transmission-corridor monitoring described in this case, parts of the study area were covered by a single viewing geometry, so the analysis prioritised the reliable delineation of deformation zones over precise quantification of displacement magnitude in those sections.[18]

3.2 Copernicus and the Sentinels

The service studied is based heavily on the use of Sentinel-1 data from the European Copernicus Programme, so a brief overview of the programme is useful to place the service in context.

Copernicus is an EU flagship programme. It began as GMES (Global Monitoring for Environment and Security) with the goal of meeting European geo-information needs. At its heart is one of the most complete operational satellite systems in the world, owned by the EU, designed and developed by ESA, and operated by ESA and EUMETSAT.

Sentinel-1 carries a Synthetic Aperture Radar operating in C-band. The mission is designed as a two-satellite constellation (Sentinel-1A and Sentinel-1B). However, following the loss of Sentinel-1B to a power-supply anomaly in December 2021, the constellation operated with a single satellite until Sentinel-1C entered service. Sentinel-1D became fully operational in 2026, and Sentinel-1A concluded operations on 30 June 2026, leaving Sentinel-1C and Sentinel-1D as the operational two-satellite constellation. This constellation history is directly relevant to the present case: during the single-satellite period, the revisit interval over a given area lengthened, and the availability of both ascending and descending viewing geometries was reduced in some regions.

[18] Rodríguez Pardo, J. A., & Upegui Pachón, J. S. (2025). Innovaciones en tecnología satelital: monitoreo de líneas de transmisión y mantenimiento predictivo con InSAR. *CIMGA 2025*, Cartagena de Indias, May 2025. Copy held by the authors.

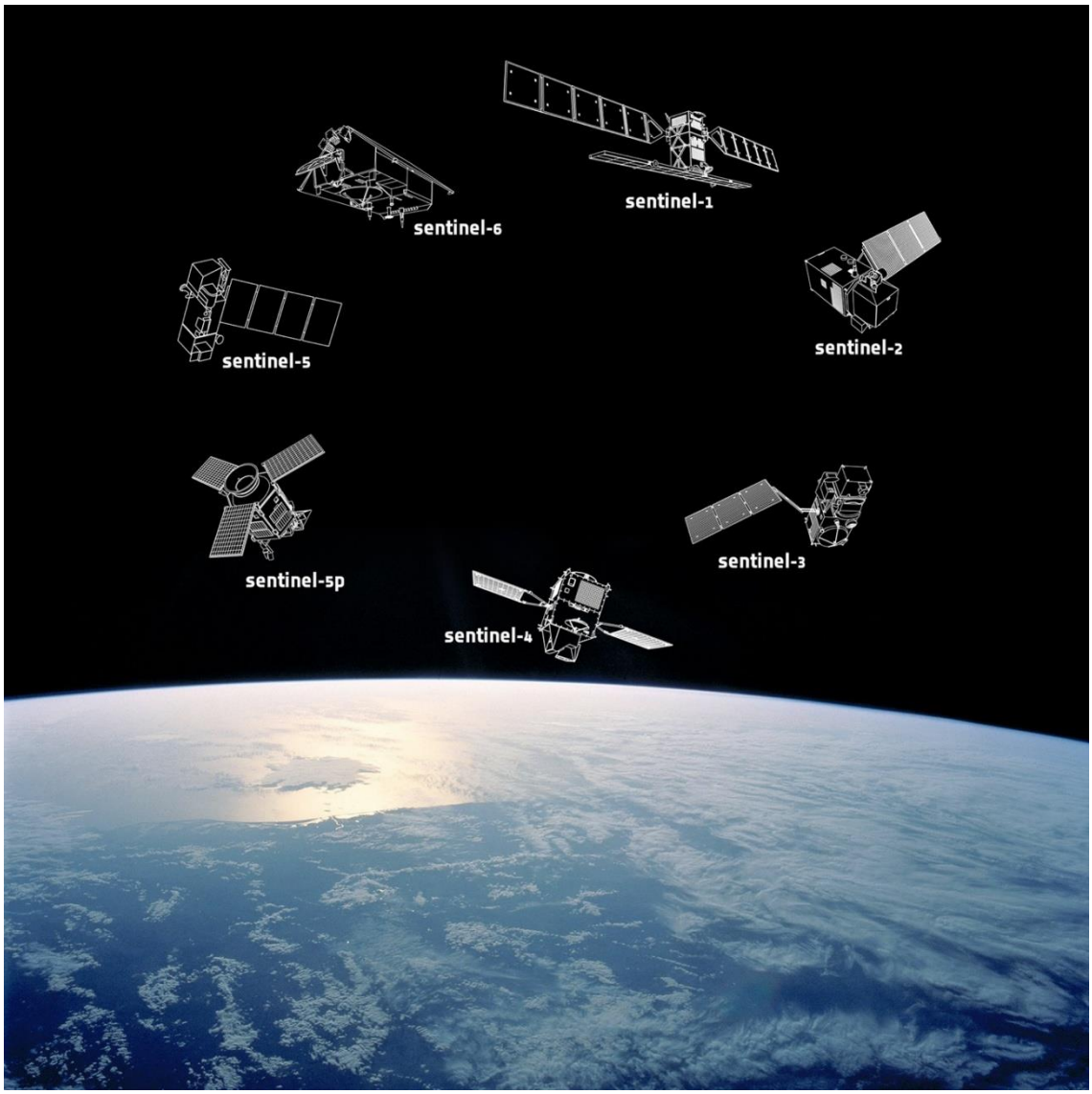


Figure 5 Current suite of Sentinel missions (ESA)

A defining feature of the Copernicus model is that Sentinel-1 data are provided under a full, free and open data policy, which makes routine, repeated monitoring economically viable in a way that commercial radar data alone would not be. This is particularly relevant for monitoring long transmission corridors, where continuous observation over wide areas would be prohibitively expensive if every acquisition had to be purchased. At the same time, free Sentinel-1 data and commercial radar data are not mutually exclusive: the open Sentinel-1 archive can serve as the continuous backbone of a monitoring service, with higher-resolution commercial radar acquisitions – such as those from missions operating in X-band – introduced selectively over specific sites where finer spatial detail or a particular viewing geometry is required. The free, wide-area data and the targeted commercial data therefore play complementary roles, with the former providing systematic coverage and the latter added where the value justifies the cost.

3.3 The Detektia service

Detektia's infrastructure-monitoring service relies almost exclusively on continuous C-band radar data from Sentinel-1; the company estimates that 90–95% of the data it uses comes from this mission, complemented by commercial radar data from PAZ and TerraSAR-X where required. Because GeoAndina has neither the internal capacity nor the intention to process raw satellite data itself, Detektia acts as the intermediary that translates complex radar data into applied geotechnical information that can be used in engineering workflows. The outputs are delivered through the company's EyeRADAR platform and, where users work in their own GIS environment, as integrated layers (Figures 6 and 7).

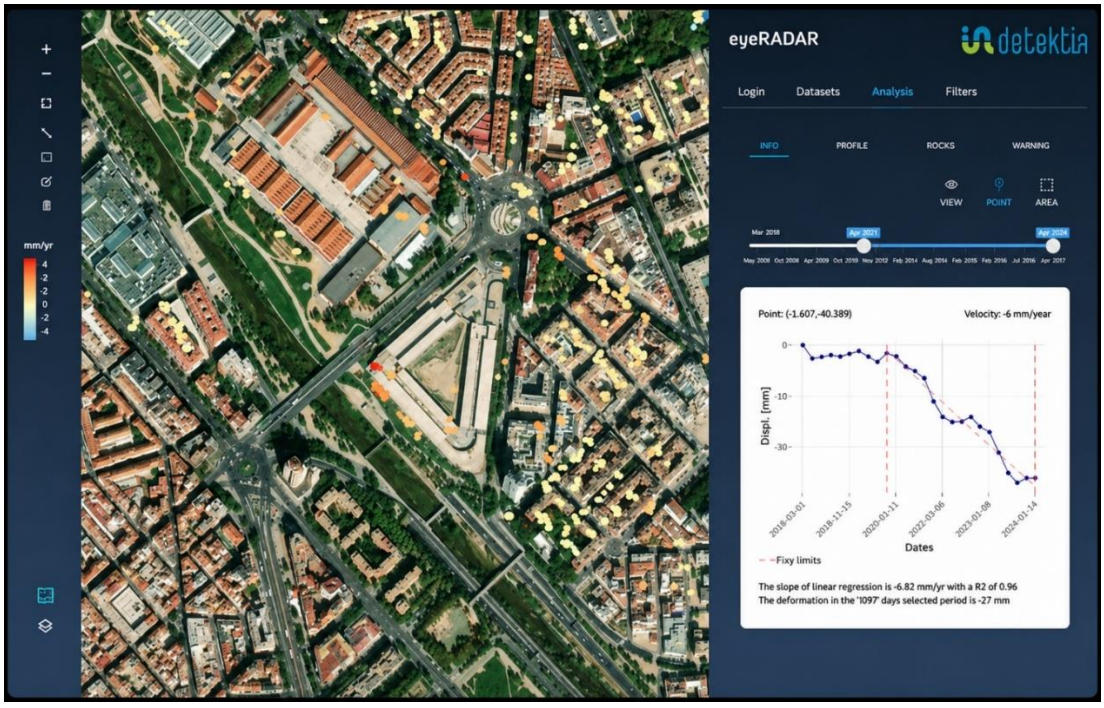


Figure 6 Detektia's EyeRADAR web platform, showing the deformation time series for a single measurement point with its fitted velocity trend. Source: Detektia

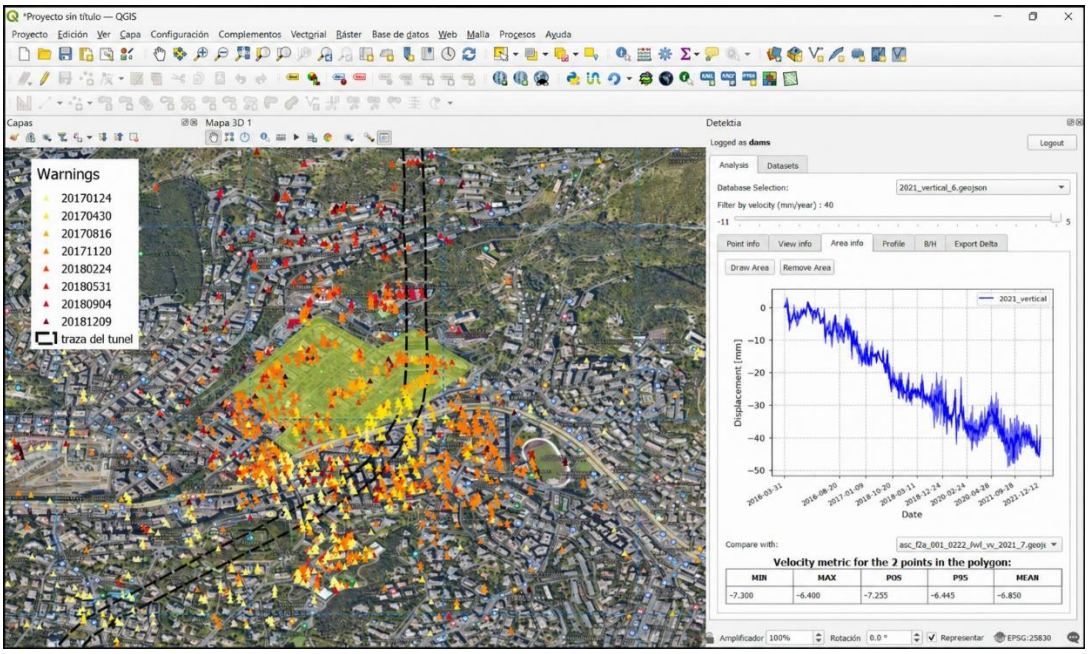


Figure 7 Detektia's InSAR outputs integrated into a desktop GIS environment, with date-coded deformation warnings and velocity statistics for a user-selected polygon. Source: Detektia

To make this operational, Detektia integrates Artificial Intelligence (AI) and Machine Learning (ML) into its processing and post-processing pipelines. This efficiency allows a lean core team of five people to manage large volumes of data; the company states that, through this use of AI, the team produces output that would traditionally require around fifteen people. The service combines InSAR outputs with external meteorological data (such as rainfall and temperature) drawn from open APIs, and with Copernicus Land Monitoring Service products including the European Ground Motion Service, Land Cover data and Digital Elevation Models.

For the Grupo Energía Bogotá powerline project, the monitoring logic is highly targeted. Out of an estimated 2,500 to 3,000 kilometres of high-tension lines, GeoAndina has identified ten critical sectors from a geotechnical perspective; four of these are currently under continuous monitoring, with six more planned. Detektia delivers the service over four areas of interest, each spanning approximately 15 to 20 square kilometres around critical towers; because instability

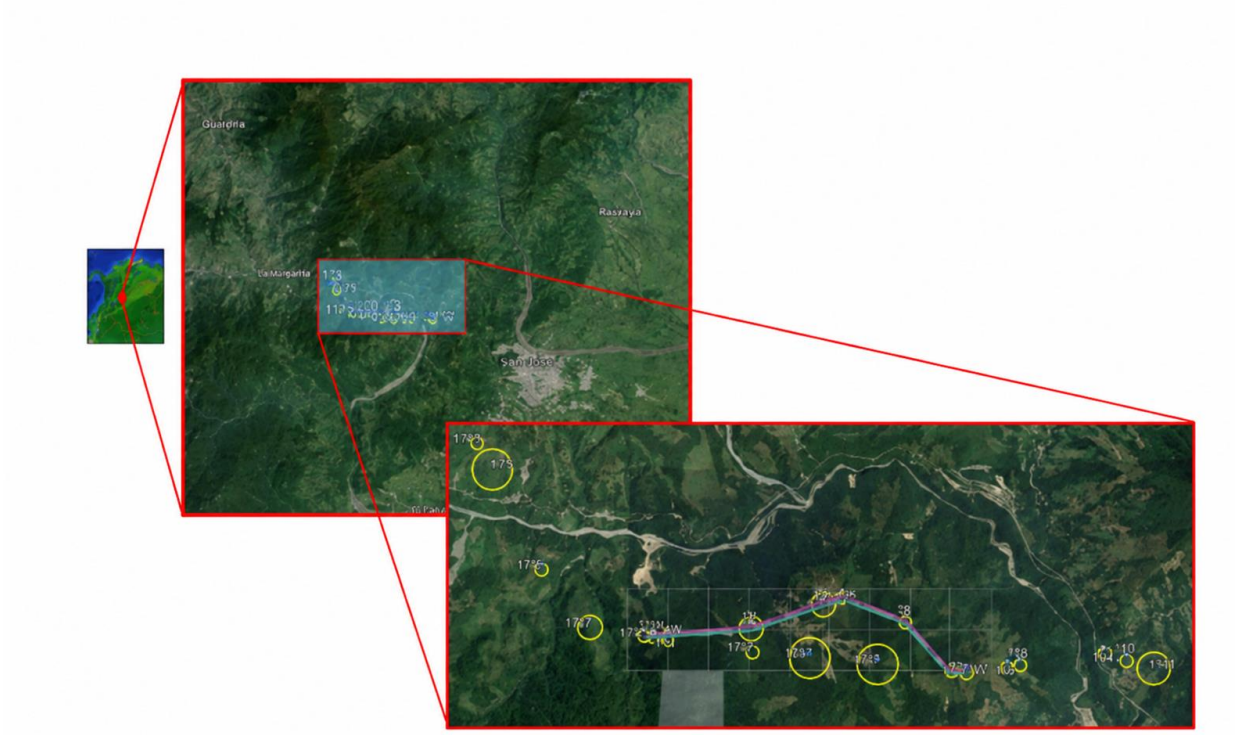


Figure 8 Extent of a monitored area of interest around critical transmission towers, with detail inset. Source: Geoandina-i SAS

may originate in larger geological structures such as nearby faults or creeping slopes, the monitored areas extend several kilometres beyond the towers themselves (Figure 8).

The revisit time of the service involves three distinct intervals:

- **Acquisition (satellite revisit).** Sentinel-1 acquires imagery over the monitored corridors approximately every twelve days under the single-satellite configuration that applied during much of the project period. With both satellites operating, the revisit is shorter, closer to **six days**.
- **Service update (reporting).** Detektia reprocesses the full InSAR time series and issues **around eight updates per area per year**, each extending the series to the present.
- **User review.** GeoAndina reviews the outputs on an approximately **fortnightly** basis, focusing on previously identified critical areas and examining the behaviour of key measurement points over time.

For each update, Detektia re-runs the InSAR analysis and extends the historical time series to the present, capturing ground-movement velocities at the millimetre-per-year level across thousands of measurement points per area. The monitored points remain broadly consistent over time, although some may change as coherence is lost through surface change or ground works. Corner reflectors are not used in this project, although Detektia has used them in a small number of other projects.

Detektia delivers these outputs through its EyeRADAR web platform and a dedicated QGIS plugin, designed so that the geotechnical team can work with the data directly rather than

through manual report exchange. The tools allow the user to project measured movements along a chosen axis of interest, to cluster measurement points, to examine the displacement history of individual points, and to test correlations between ground movement and external variables such as precipitation and temperature. GeoAndina, which holds the local geological expertise and terrain knowledge, performs the final geotechnical interpretation that determines the actual risk to the infrastructure.

Field verification is integral to the workflow. When the satellite data flag a concentration of deformation points or an unexpected anomaly, field teams investigate to confirm the physical evidence on the ground, confirming whether the satellite has detected a true structural threat, such as river scour undermining a foundation, or a less critical surface change. The historical deformation maps support GeoAndina's recommendations rather than replacing the engineering judgement that produces them.

In the monitored corridor, this workflow has surfaced concrete, actionable findings. The asset owner's account of one such area describes a study polygon of approximately 16 km^2 containing fifteen high-tension tower sites.[19] Line-of-sight deformation rates of the order of 7 to 21 mm per year, at an accuracy of about ±2 mm per year, have been reported for monitored tower sites on Colombian transmission corridors from a Sentinel-1 archive extending back to 2014.[20] Across the studied tower sectors, the analysis identified several distinct zones of accumulating deformation, each tied to a specific structure: lateral erosion of a drainage channel advancing towards one tower foundation; slow creep on a slope above another tower that continued to progress across successive analysis periods; and reactivated mass-movement processes associated with natural drainage lines close to the line. In each case the satellite-flagged concentration of deformation points (Figure 9) was checked against field inspection, which confirmed whether the signal corresponded to a genuine structural threat – such as scour undermining a foundation – or to a more superficial change such as vegetation movement or localised surface creep. The value of the approach lies in this prioritisation: the monitoring directs limited field and engineering effort to the specific tower sites where instability is developing, rather than across the full length of the corridor.

[19] Rodríguez Pardo, J. A., & Upegui Pachón, J. S. (2025). Innovaciones en tecnología satelital: monitoreo de líneas de transmisión y mantenimiento predictivo con InSAR. *CIMGA 2025*, Cartagena de Indias, May 2025. Copy held by the authors.

[20] Salazar, H. A., & Restrepo, V. H. (2020). Remote sensing monitoring applications for landslides in infrastructure projects in Colombia. *SCG-XIII International Symposium on Landslides*, Cartagena, Colombia, 15–19 June 2020.https://www.issmge.org/uploads/publications/105/106/ISL2020-145.pdf

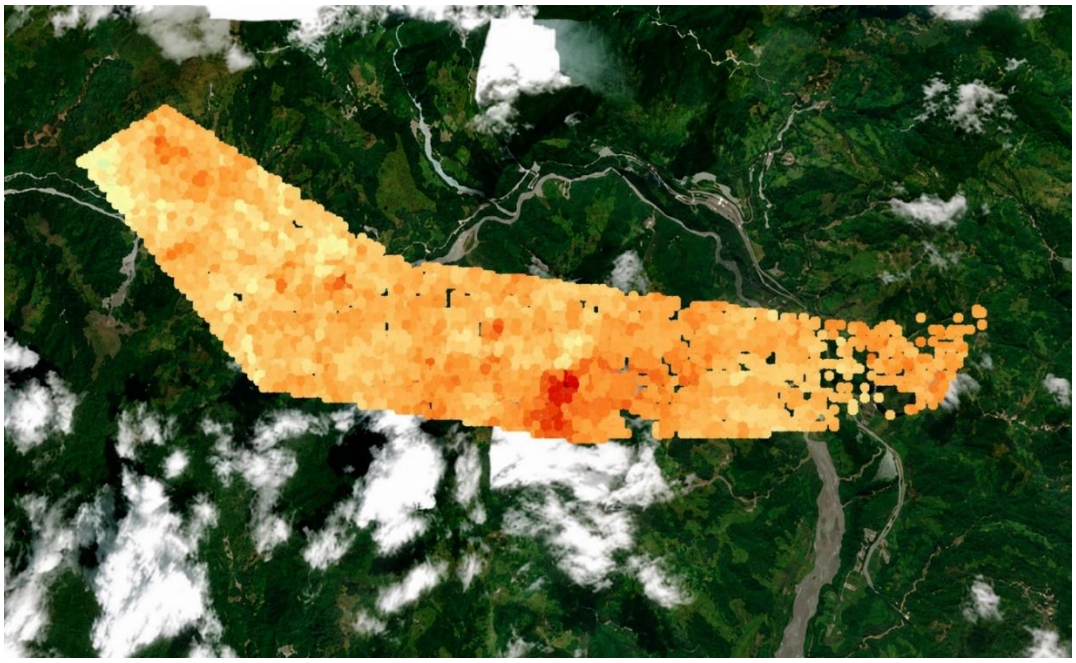


Figure 9 Deformation map of a monitored tower sector, showing colour-coded displacement points (Geoandina-i / Detektia, via CIMGA, 2025)

The asset owner has documented its own use of the approach in a 2025 technical paper authored by Enlaza and Grupo Energía Bogotá (GEB) staff, presented at the International Congress on Maintenance and Asset Management (CIMGA). The paper describes continuous InSAR monitoring of a transmission corridor and reports that the approach reduces the need for frequent physical inspections and helps to avoid penalties for unsupplied energy.

The same technique has been applied on another Colombian transmission corridor. There, monitoring a strip of energy towers over the course of a year, with updates every twelve days, revealed specific annual displacement rates and zones of terrain creep. On the basis of this objective evidence, the asset owner and GeoAndina were able to take highly targeted engineering decisions, opting to relocate the most vulnerable towers by means of a variant route while applying focused geotechnical reinforcement works on others, thereby reducing the risk of sudden structural failure[21]. Both applications are documented by the actors involved, and the CIMGA evidence is carried into the benefit assessment in Section 5.

3.3.1 Future Evolution of the Service

Following the deployment of its monitoring services in Latin America and Spain, Detektia is expanding its technical and educational capabilities. The company has developed an algorithm

[21] Restrepo Botero, V. H., & Piedrahita Ospino, J. C. Aplicaciones de instrumentación geotécnica y estructural para grandes proyectos de infraestructura. Noticreto, no. 170, pp. 38–41 (ASOCRETO). https://noticreto.com/Noticreto/170/46-47-48-49-Tecnologia_1_170.pdf

that improves three-dimensional InSAR scatterer localisation by fusing radar data with LiDAR point clouds, work recognised by a 2024 Cassini Challenge award. It is contributing a ground-stability layer to a digital-twin initiative for the city of Madrid and is participating in the Horizon Europe-funded ‘Space4Cities’ project. It has also begun publishing services on the European Commission’s Destination Earth (DestinE) initiative. Detektia has also established an online training course, the "InSAR Academy", which it intends to make more widely accessible through the ESA Network of Resources, including for students and professionals in developing countries.

A particularly relevant recent development for this case is the launch in 2026 of Detektia’s MoMo (Motion Modeling) service on the DestinE platform. MoMo models InSAR deformation time series together with climate data and other relevant variables, with the explicit aim of moving beyond the measurement of displacement towards interpreting when, where and why deformation occurs. The implications of MoMo for the kind of monitoring described in this case are discussed in Section 7.4.

4 Understanding the value chain

4.1 Description of the value chain

The core value chain in this case begins with the generation of satellite-derived ground-deformation information and extends through its operational use, downstream commercial application, and wider societal effects (Figure 10). At **Tier 1** sits **Detektia**, the **service provider that processes Sentinel-1 radar data into interpretable ground-deformation information** and delivers it through its EyeRADAR platform and associated tools. At **Tier 2** sits **GeoAndina**, the **primary user**, a **geotechnical engineering group that interprets the deformation information** within a wider engineering context and converts it into recommendations. At **Tier 3** sit **Grupo Energía Bogotá (GEB) and its transmission company Enlaza**, the **asset owner that receives those recommendations** and acts on them through inspection, maintenance and intervention decisions. At **Tier 4** sit the **citizens** and the **wider economy that depend on a reliable electricity supply** and therefore benefit, indirectly, from better-managed transmission infrastructure.

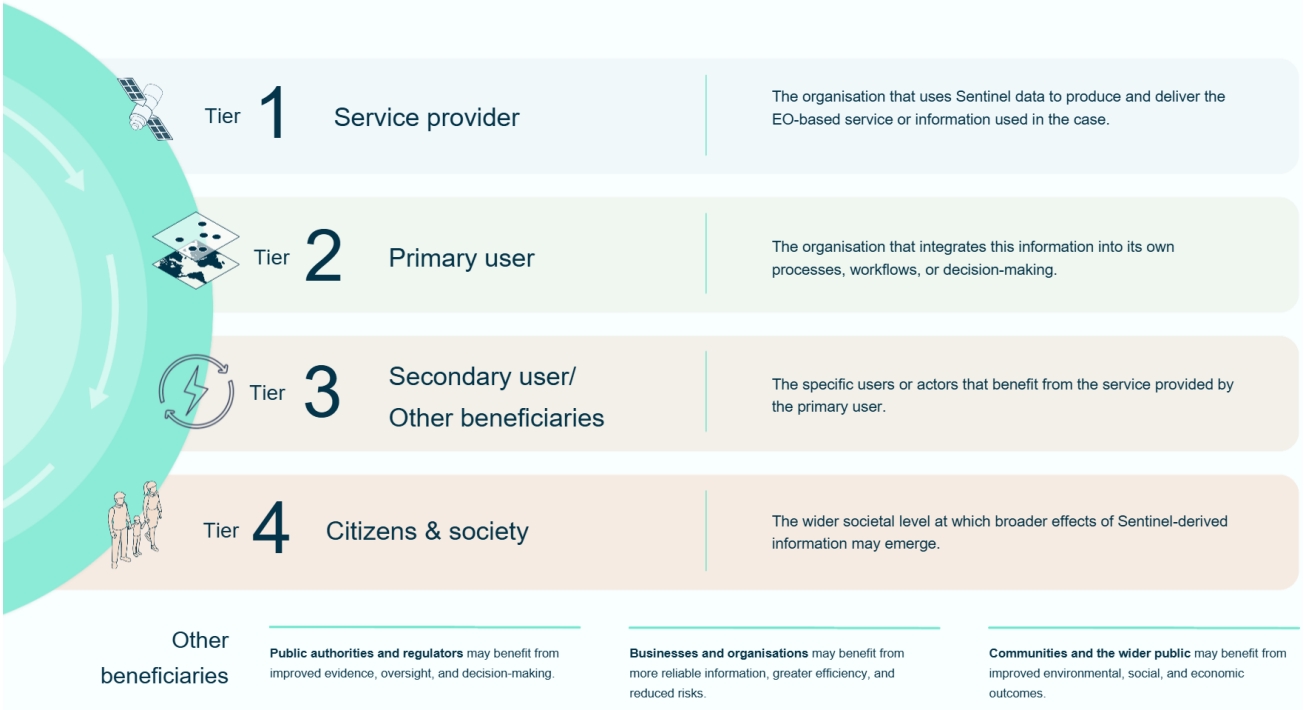


Figure 10 The value chain of the analysed case on powerline monitoring in Colombia

A defining feature of this value chain is the clean division of labour between Tier 1 and Tier 2. Detektia provides geospatial information and analytical tools, and GeoAndina performs the final geotechnical interpretation. This boundary matters for the benefit assessment in Section 5, because it determines where in the chain each type of value is created and to whom it should be attributed.

4.2 The actors

4.2.1 Service Provider (Tier 1) – Detektia

Detektia is a Spanish small enterprise founded in 2019 as a spin-off from the Civil Engineering School of the Universidad Politécnica de Madrid (UPM). It was created by five co-founders, most of them connected to the university's research line on InSAR, and it remains a deliberately small company of five full-time staff. The company specialises in InSAR for infrastructure and ground monitoring and describes its core business as providing insights into the behaviour of clients' physical assets, delivered as analytical reports, alerts, or direct access to its tools depending on the client.



Figure 11 Detektia's core team

The company's origin is closely tied to infrastructure risk. The founders have described how the idea for Detektia was shaped by an episode in 2018 in which they crossed a bridge shortly before it collapsed, which sharpened the question of how such failures can occur without prior warning. This framing should be read carefully: it is a genuine motivating story for the company, but it is not a claim that InSAR can predict structural collapse. As Section 3 sets out, InSAR can detect deformation signs but does not, on its own, predict failure.[22]

Detektia's relationship with Copernicus is foundational rather than incidental. The company began using Sentinel-1 data since its creation and states plainly that, without free and open Copernicus data, it would probably not exist. Today around 90–95% of the data it uses comes

[22] EARSC / Evenflow (2022), *Highways Management in Italy*, Sentinel Benefits Study (SeBS-CR-002).

from Sentinel-1, complemented by commercial radar data from PAZ and TerraSAR-X where required, and by Copernicus Land Monitoring Service products including the European Ground Motion Service, Land Cover and Digital Elevation Models. In the company's own estimate, roughly half of the value delivered through the service would not exist without the Sentinel data input, with the remainder arising from its own processing, algorithms and expertise. This is an attribution of the delivered service's value to its inputs, not a statement about the company's value: Detektia does not resell Sentinel data, and its commercial value lies entirely in what it builds on top of the free data layer. These are two different measures: a 100% enabling dependence (the company could not operate without the data) and a roughly 50% attribution of service value to the data input.

Detektia delivers its service to GeoAndina through access to its EyeRADAR web platform and a QGIS plugin, which include functions to project movements along an axis of interest, to cluster measurement points, and to check correlations with variables such as precipitation and temperature. Beyond this case, the company has developed proprietary (though unpatented) tools; its wider innovation activity and roadmap are set out in Section 3.3.1. Its principal markets are Mexico, Colombia and Spain.

4.2.2 Primary user (Tier 2) – GeoAndina

GeoAndina is not a single firm but a group of three Colombian engineering companies working across large infrastructure projects in transport, energy generation and transmission, and mining. The group comprises Geotecnia Andina, founded in 2010 and focused on geotechnical studies, design and construction support; GeoAndina I, founded in 2014 and focused on innovation, instrumentation and in-situ testing, which also leads the group’s Earth-observation and InSAR activities; and Vits Andina, which develops technological systems for transport infrastructure.



Figure 12 GeoAndina team

The group delivers engineering services in the form of reports and technical drawings (Figure 13). It does not develop its own monitoring technologies but integrates and applies external ones within its engineering practice, positioning itself around what it calls “Engineering 4.0” and working across the full project lifecycle, from planning and design through construction support to operation and maintenance. In recent years it has extended its activity into Chile, Panama and Peru.

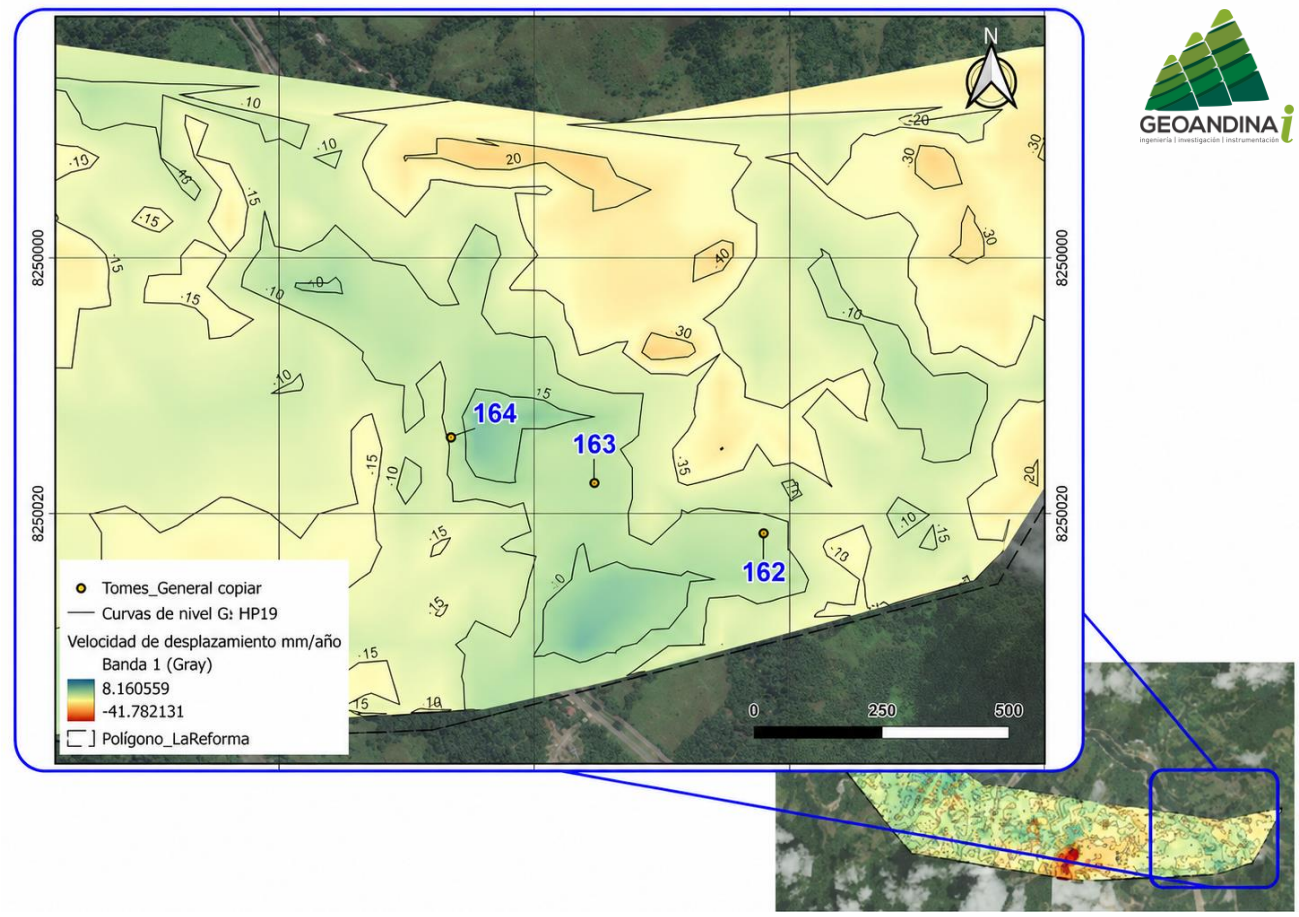


Figure 13 Processed terrain and geotechnical analysis of a monitored area. Source: Geoandina-i SAS.

GeoAndina’s move into Earth observation grew directly out of the Colombian context: young, unstable mountainous terrain, very high rainfall, marked seismicity, and a population and economy concentrated in the mountains. The turning point was the 2010–2011 La Niña episode, during which Héctor Salazar (who is now the managing director of Grupo Geoandina) was managing a motorway concession and dealt with the consequences of widespread landslides at first hand. The firm began looking for a technology that could read terrain behaviour over wide areas, and identified satellite interferometry as the answer. Its first practical application in Colombia came in 2014-2015, on a ten-kilometre stretch of the Pasto–Rumichaca motorway in the south of the country, near the Ecuadorian border, for a concession run by the Spanish operator Sacyr, which was already familiar with the technology from its use in Europe.



Figure 14 GeoAndina monitoring of the La Reforma transmission-line corridor. Source: Restrepo Botero & Piedrahita Ospino, Noticreto no. 170, pp. 38–41 (image courtesy of Geoandina i SAS).

GeoAndina works with an external InSAR provider by choice: it has neither the capacity nor the wish to process raw satellite data itself, preferring to concentrate on the engineering interpretation that is its core business. Before working with Detektia, it had worked with other European InSAR providers. Its decision to move to Detektia rested on three things it singled out in the interview: Detektia's advanced use of AI and machine learning in InSAR processing, which it saw as the main differentiator; the practical advantage of working in Spanish; and Detektia's perceived technological lead.

4.2.3 Transmission asset owner (Tier 3) – Enlaza / Grupo Energía Bogotá

Grupo Energía Bogotá (GEB) is the asset owner at the centre of the downstream value chain, with electricity transmission delivered through its transmission company, Enlaza. GEB is a major Latin American energy group; a controlling stake of approximately 65.68% is held by the Capital District of Bogotá, which means that the transmission assets in question are, to a substantial degree, publicly owned infrastructure. The protection of asset value at this tier therefore also has a public-investment dimension. While no public book value exists for the specific assets, their scale can be dimensioned from the event-cost figures used in Section 5: tower reconstruction alone is estimated at €1.1–1.9 million per structure, and a single major terrain-driven event on a comparable line represents an exposure of several million euros (Section 5.2.3).



Figure 15 Electricity-transmission towers operated by Enlaza (Grupo Energía Bogotá) in mountainous Colombian terrain (Tesalia–Alférez 230 kV line). Source: Enlaza – Grupo Energía Bogotá.

GEB and GeoAndina have worked together on transmission-line monitoring since an initial phase covering roughly 40 kilometres of lines between 2019 and 2021. The current contract covers a network of approximately 2,500 to 3,000 kilometres of high-voltage lines, within which ten critical sectors have been identified from a geotechnical perspective, four currently under continuous monitoring and six more planned. As the asset owner, GEB is responsible for inspections, maintenance and interventions, and it integrates terrain-related risk within a formal corporate risk-management framework that identifies and treats strategic risks through preventive controls.[23] Satellite-derived deformation information functions as one input supporting the mitigation of terrain-related threats before they materialise into structural failures.

A documented application of this approach, authored by the asset owner itself, is the 2025 CIMGA paper by Enlaza and GEB staff, which describes continuous InSAR monitoring of a transmission corridor and reports that it reduces the need for frequent physical inspections and

[23] Grupo Energía Bogotá (2021), *2020 Corporate Governance Report* (comprehensive risk-management system).

helps avoid penalties for unsupplied energy.[24] These two reported mechanisms anchor the economic assessment at Tier 3 in Section 5.

4.2.4 Citizens and society (Tier 4)

The final tier comprises the citizens, communities and economic activity that depend on reliable electricity transmission. The scale of that dependence is national in character. Colombia's electricity supply is delivered principally through the National Interconnected System (SIN), with the remaining, largely remote areas served by isolated systems. National electricity coverage reached 93.12% of dwellings in 2024, rising to 98.71% in urban areas.[25] The SIN is carried by more than 28,000 kilometres of high-voltage transmission lines operating between 57.5 kV and 500 kV, against a national peak demand of around 10 GW.[26] High-voltage transmission corridors of the kind monitored in this case are therefore part of the backbone on which the great majority of the population depends, even though any single corridor feeds the interconnected system as a whole rather than a discrete set of end users. The role of an individual corridor can nevertheless be illustrated with the Tesalia–Alférez 230 kV line (Figure 15): 201 kilometres and 411 towers crossing eleven municipalities in Huila, Tolima and Valle del Cauca, connecting the 400 MW El Quimbo hydroelectric plant to the country's southwest, and creating a new 230 kV power-flow path between the Cauca–Nariño and Huila–Tolima subareas that relieves congestion on the regional 115 kV network.[27,28]

A major transmission failure on a high-voltage line can interrupt supply across wide areas, with consequences that extend well beyond the cost of repairing the line itself: disruption to households, public services and economic activity, and, where outages are prolonged or repeated, a measurable economic and social cost. This exposure is heightened in the Colombian context by the same terrain and climate conditions that drive ground instability along the corridors, and by the system's reliance on hydropower, which leaves it sensitive to hydrological stress and, in turn, places a premium on the reliability of the transmission network that moves power from where it is generated to where it is consumed.

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[24] Rodríguez Pardo, J. A., & Upegui Pachón, J. S. (2025). Innovaciones en tecnología satelital: monitoreo de líneas de transmisión y mantenimiento predictivo con InSAR. *CIMGA 2025*, Cartagena de Indias, May 2025. Copy held by the authors.

[25] UPME, Índice de Cobertura de Energía Eléctrica (ICEE), 2024 results. https://www.minenergia.gov.co/es/sala-de-prensa/noticias-index/colombia-alcanza-9312-de-cobertura-electrica-tras-llevar-energia-a-539351-nuevos-hogares-y-registrar-el-mayor-avance-en-la-ruralidad/

[26] CIGRE/ELECTRA, Challenges of Power System Operations in Colombia. https://electra.cigre.org/320-february-2022/global-connections/challenges-of-power-system-operations-in-colombia.html

[27] Enlaza – Grupo Energía Bogotá, Tesalia–Alférez 230 kV (UPME 05-2009). project information, www.enlaza.red

[28] XM (2023), declaration of commercial operation of the Alférez–Tesalia 230 kV double circuit, 13 December 2022, www.xm.com.co

5 Assessing the benefits

The benefit assessment follows a value-chain logic and examines how Sentinel data contribute to operational outputs, user actions, and resulting benefits across the different tiers of the case. The analysis focuses on six benefit dimensions where relevant to the case: economic, environmental, societal, regulatory, innovation/entrepreneurship and science/technology related benefits.

For each identified benefit, the assessment seeks to clarify five elements: (i) the stakeholder experiencing the benefit, (ii) the mechanism through which the benefit is created, (iii) the indicator or proxy used to assess it, (iv) the evidence on which the assessment is based, and (v) the extent to which the benefit can be attributed to the Sentinel-enabled service. Where sufficient evidence is available, models are developed and used to estimate indicative orders of magnitude. Where this is not possible, benefits are described qualitatively and linked to concrete operational effects.

Particular attention is given to attribution. The report does not assess the value of the overall service in generic terms, but rather examines the extent to which Sentinel-derived inputs enable, improve, scale, or reduce the cost of the service compared with plausible alternatives or with a situation in which such information would not be available.

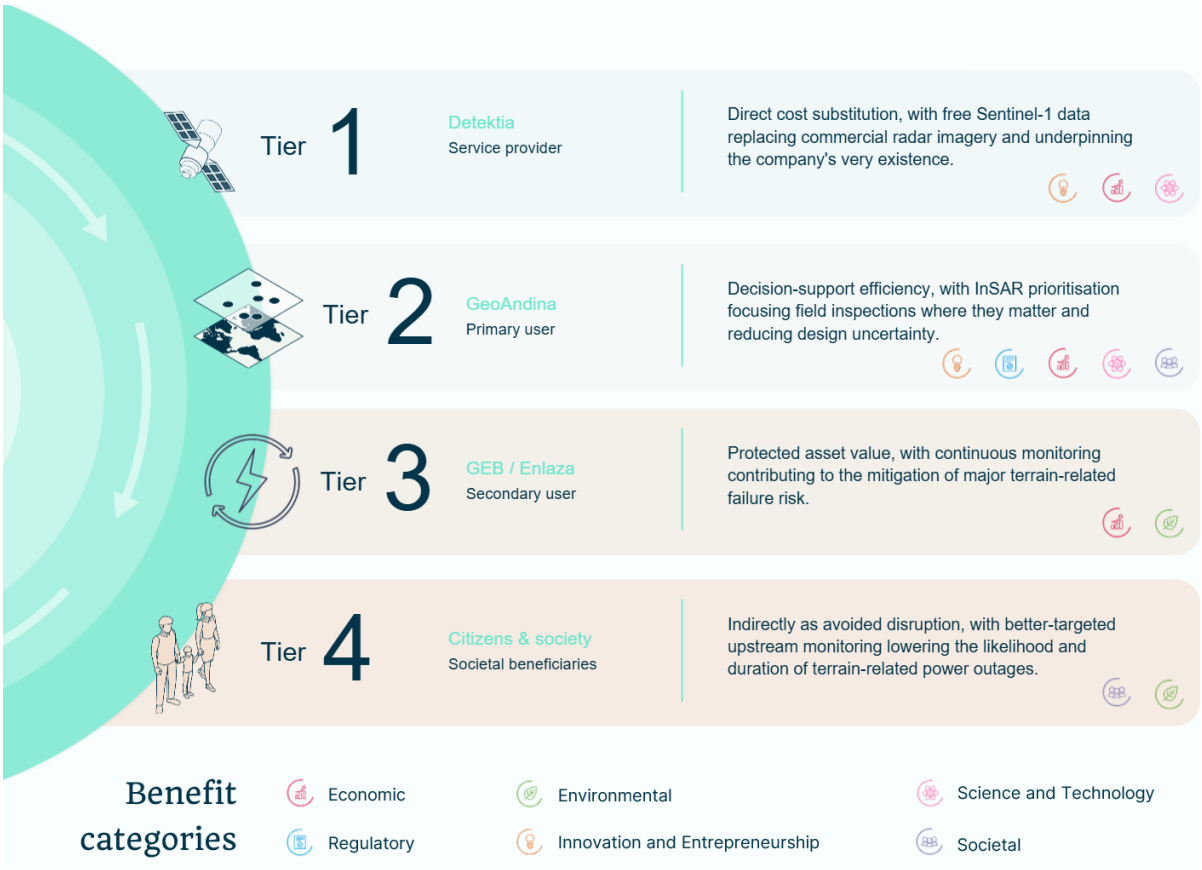


Figure 16 Depiction of the benefits along the value chain

5.1 Overview

This chapter takes each tier in turn, applies the six benefit dimensions and the five-element discipline set out above,[29] and then summarises the results by dimension.

Three points of method apply throughout. First, the benefit cascade is treated as sequential: value created at one tier is not re-counted at the next. Second, attribution is conservative and given for each benefit. Third, where a figure rests on a benchmark transferred from another setting rather than on operational data specific to this case, that is stated at the point of use and revisited in Section 6.3. The economic figures in this chapter rest on a small number of named assumptions, set out in full in Annex 2.

5.2 Benefits along the value chain

5.2.1 The service provider (Tier 1) – Detektia

Counterfactual. Without free Sentinel-1 data, an equivalent monitoring service would have to rely on commercial radar imagery. Detektia states that, at the company level, it would probably not have been founded without access to free Sentinel data. For the quantified assessment, however, the narrower counterfactual holds the service specification constant and estimates the cost of the commercial imagery that would otherwise have been required.



The principal quantifiable benefit at Tier 1 is the avoided cost of commercial radar data enabled by the use of free Sentinel-1 data. This benefit is therefore captured as an avoided commercial-data-cost indicator. **Under the quantified counterfactual, which holds the service specification constant,** Detektia estimates that each service update for the GeoAndina contract would require commercial imagery costing approximately €10,000 per area update. With eight updates per year across four areas, this amounts to approximately €320,000 per year (€10,000 × 8 × 4). Around fifty updates delivered to date correspond to approximately €500,000 in cumulative avoided data costs. The attribution is direct: this cost would arise only if free Sentinel-1 data were unavailable and an equivalent service relied on commercial imagery. The €320,000 is not a saving on Detektia's fee, but an additional data cost that the client would face on top of the processing and interpretation costs.

[29] Sawyer, G., Mamais, E., and Papadakis, D. (2022). The Six Dimensions of Value Associated to the use of Copernicus Sentinel Data: Key Findings from the Sentinel Benefits Study. Frontiers in Environmental Science, 10, 804862. https://doi.org/10.3389/fenvs.2022.804862

Two separate attribution statements sit alongside this estimate. Detektia states that the company would probably not exist without free Sentinel data, representing a 100% enabling dependence, and that approximately 50% of the value delivered to clients is attributable to the data, with the remainder arising from its processing and expertise. **These represent three distinct measures: the €320,000 is an avoided cost, the 50% is the company's own attribution of delivered-service value to the Sentinel data input, and the 100% describes the enabling dependence of the business on Sentinel data.** The two percentages are qualitative attribution statements and are not applied to the €320,000 avoided-cost estimate. Only the avoided commercial-data cost enters the quantified economic assessment.



Innovation and Entrepreneurship Benefits

The benefit at this tier is high, and the mechanism is enabling rather than incremental. Free Sentinel-1 data lowered the cost of market entry sufficiently for a five-person university spin-off to become commercially viable, sustaining five highly skilled jobs and supporting the company's participation in Horizon Europe research and development projects. The productivity the company achieves from that base – including the ability of its five-person team to manage a growing portfolio of projects and clients without proportional staff expansion – rests on its own AI-assisted processing, software and expertise (Section 3.3).

The innovation and entrepreneurship benefit also includes the conversion of Detektia's internally developed processing and post-processing capabilities into licensable software, APIs and analytical tools. The company's technological development has received external recognition through innovation challenges and accelerator programmes, including a Cassini challenge award for an algorithm that combines InSAR and LiDAR data to improve scatterer localisation and three-dimensional visualisation. These achievements relate to Detektia's wider Sentinel-based activities rather than specifically to the GeoAndina contract.



Science and Technology Benefits

Detektia has contributed to peer-reviewed publications on ports and structural-health monitoring and has co-authored dam-related work, although none of these publications directly concerns the GeoAndina case. **Its contribution to the advancement and diffusion of InSAR practices is therefore real but relates to the company's wider activities rather than specifically to this case.**

Detektia also contributes to the diffusion of InSAR knowledge through its online Academy, which provides professional training on InSAR interpretation, the European Ground Motion Service and associated analytical tools. The company intends to broaden access to this training through ESA's Network of Resources. **This capacity-building benefit also relates to Detektia's wider activities and is not specific to the GeoAndina case.**

5.2.2 The primary user (Tier 2) – GeoAndina

Counterfactual. Without satellite screening, GeoAndina would prioritise inspection from terrain knowledge, historical records and site visits alone, at the campaign frequency and cost set out below, and would dimension works with the higher safety factors that sparse data require.

Economic Benefits

Three effects generate economic value at Tier 2: a reduction in field-inspection effort, improved design efficiency through reduced uncertainty, and a separate saving in corridor planning, each discussed in turn.

Reduction in field-inspection effort

By using InSAR to identify where deformation is concentrated, GeoAndina can direct physical inspection to the corridor sections that warrant it rather than covering the line uniformly (Figure 17). The proxy range adopted is a **50–60% reduction in inspection effort**. The upper bound is drawn from a peer-reviewed highway-slope study that reports a 60% reduction in monitoring cost when InSAR replaces traditional survey methods;[30] this is a highway-context figure, transferred here as a proxy for inspection-effort reduction. The lower bound of 50% is adopted as a deliberately conservative position. For this specific corridor, the direction of the effect is corroborated by the asset owner's own CIMGA paper, which reports that the approach reduces the need for frequent physical inspections.[31]

[30] Duan, L., Lim, H. S., Mohd Sharoni, S. M. H., Chen, M., et al. (2025). Assessing highway slope stability risks using InSAR: a case study in Bijie, China. *Geocarto International, 40*(1), 2521661. https://doi.org/10.1080/10106049.2025.2521661

[31] Rodríguez Pardo, J. A., & Upegui Pachón, J. S. (2025). Innovaciones en tecnología satelital: monitoreo de líneas de transmisión y mantenimiento predictivo con InSAR. *CIMGA 2025*, Cartagena de Indias, May 2025. Copy held by the authors.

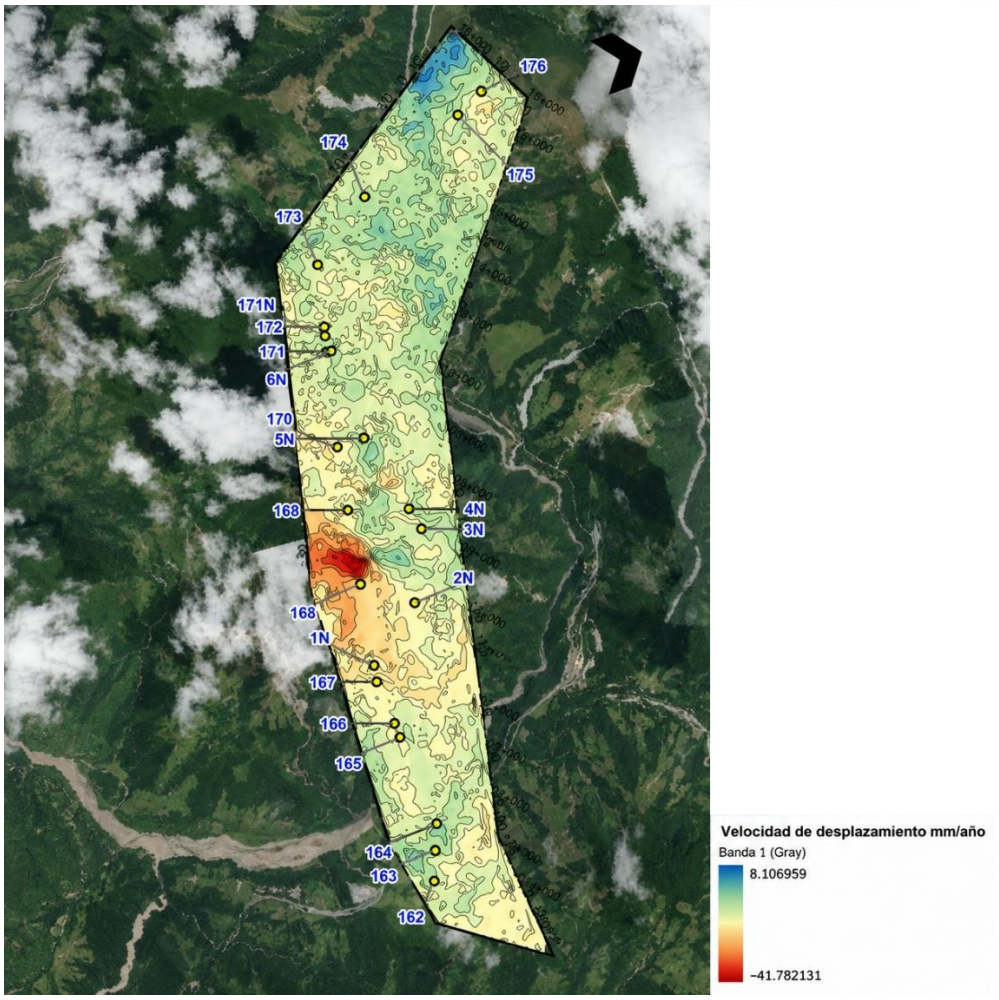


Figure 17 InSAR-derived deformation along a monitored slope, colour-coded by displacement; the concentration of movement is what directs field inspection. Source: Geoandina-i SAS

The share of this reduction attributable to the satellite depends on the baseline that preceded it. Where a landslide susceptibility model or historical displacement record was already in place, part of the prioritisation benefit would have been captured through conventional methods, and the marginal contribution of InSAR is correspondingly smaller. That condition does not hold on to these corridors. The asset owner's own account records an initial InSAR pilot between 2019 and 2021, resumed with periodic data processing in 2024, and states that the terrain reference condition was established through a three-year multitemporal analysis of satellite imagery. The prior deformation record was therefore generated by the satellite rather than existing independently of it, and no pre-existing susceptibility model is referenced. On this basis, 50% is adopted as a conservative working assumption within the proxy range. It should not be interpreted as a case-specific measured reduction.

This baseline effect does not imply that the benefit declines once the reference condition is established. The reference condition is what makes each subsequent update interpretable – distinguishing new or accelerating movement from established background behaviour – and the prioritisation benefit recurs with each monitoring cycle rather than being consumed by the initial

characterisation. What the baseline affects is attribution: because the satellite itself generated the prior deformation record, the marginal contribution of InSAR on these corridors is high; on corridors where an independent susceptibility model already existed, it would be lower.

To monetise this reduction, the effort indicator is applied to a counterfactual inspection programme built from external benchmarks, the operator's own visit-level data not being available. The estimate rests on three inputs, each stated as an explicit assumption:

- **Counterfactual inspection frequency.** No transmission-specific or Colombian standard prescribes a campaign frequency. Taking the Network Rail hazard-category cadence for at-risk slopes, of every two to ten years, as a lower reference,[32] and reading it against the landslide criticality of the Colombian Andes, a baseline of **one to two campaigns per critical area each year** is assumed. Both the primary user and a transmission-line geotechnical specialist confirmed this as plausible: GeoAndina endorsed the one-to-two baseline, noting that campaigns increase during the wet season when landslides require additional inspection, while the specialist described Colombian practice as ranging from annual or biannual reviews on stable corridors to quarterly or monthly inspections on unstable ones.
- **Cost per campaign.** The dominant cost driver is access. A vehicle-access campaign is estimated at roughly USD 2,000–6,000, rising above USD 4,000 per day where roadless terrain requires helicopter support.[33] Labour is a material cost rather than a marginal one: GeoAndina noted that inspection frequently requires crews to cover several towers on foot over extended periods where vehicles cannot reach, which raises the number of field days and the associated labour, per-diem and payroll costs.[34] On this basis, a single campaign is estimated at approximately **€2,500 with vehicle access and €11,000 or more by helicopter** (at USD 1 ≈ EUR 0.88, June 2026).
- **Reduction in inspection effort applied.** A 50% reduction is adopted for the monetisation, corresponding to the conservative end of the 50–60% proxy range established above. The assessment assumes that this reduction in inspection effort produces a proportional 50% reduction in campaign cost. This proportional relationship has not been verified against GEB's actual visit-level cost records.

On the conservative combination of one to two campaigns per area, of which InSAR prioritisation avoids about half, at vehicle-access cost across the four monitored areas, the avoided field-

[32] Maleki, Z.R. et al. Geophysical Survey and Monitoring of Transportation Infrastructure Slopes (TISs): A Review. *Geosciences* 2025, 15, 220. https://doi.org/10.3390/geosciences15060220

[33] Helicopter inspection ~USD 4,000+/day (AeroViews, 2026). https://aeroviews.co/industries/power-line-drone-inspection-services/

[34] Engineer ~COP 3–7M/month (Indeed; Universidad Cooperativa de Colombia); topographer ~COP 2.5M/month (Indeed). EUR 1 ≈ COP 3,950 (Wise, June 2026).

inspection cost is estimated at **€5,000–10,000 per year**, and higher once the labour component GeoAndina emphasises is fully counted. On the specialist's upper range with helicopter access, it reaches approximately **€90,000–260,000**. We adopt the lower figure as the headline estimate; the upper marks the ceiling that would apply if that higher frequency and helicopter access were the norm across the monitored areas. The estimate is sensitive to inspection frequency and access mode, which is why it is given as a range with its assumptions stated. The transmission-line geotechnical specialist also noted that InSAR can be limited in detecting slow deformation on lattice-steel towers (Section 6.3). Because the field campaigns are run by GEB rather than GeoAndina, this saving is **counted once, at Tier 3**, in the summary.

Improved design efficiency through reduced uncertainty

The second effect is improved **design efficiency through reduced uncertainty.** With only sparse data, GeoAndina managed uncertainty through **higher safety factors**, which could lead to conservative, over-dimensioned tower-foundation and slope-stabilisation designs. Richer and **more precise deformation information** can support lower but better-founded safety factors and therefore leaner works. This benefit is evidenced qualitatively but is not monetised; a possible future route to monetisation, suggested in review, would be through insurance costs, if premium data for comparable assets became available.

A separate benefit arises in **corridor planning**. GeoAndina reported that using InSAR to **identify optimal corridors without extensive fieldwork** can save "hundreds of thousands" of euros. Approximately €200,000 is retained as an illustrative lower-end estimate for a major corridor-planning exercise. The available evidence does not establish how frequently such exercises occur, whether the same saving applies to reinforcement design, or what share is attributable specifically to Sentinel-1. The figure is therefore not annualised and is not included in an aggregate total.



A genuine regulatory potential exists here, though it remains unrealised and only partly attributable to this service. GeoAndina has promoted the adoption of Earth observation in Colombian infrastructure practice since 2014–2015, well before the Sentinel-enabled monitoring examined in this case began, and has proposed guidelines and frameworks for integrating EO and monitoring technologies into national practice. That advocacy rests on InSAR practice generally rather than on this contract; what the case adds is an operational demonstration on a national transmission network that strengthens the argument. Institutional uptake is starting: INVÍAS's ongoing update of its technical manuals, including the Manual de Estabilidad de Taludes, incorporates InSAR among recognised survey techniques, and the

corredor geotécnico concept is now defined in INVÍAS risk-management documentation.[35] Neither GeoAndina's proposals nor the INVÍAS updates, still under consultation, are yet binding standards, so the mechanism by which better ground-motion information could support better regulation is present but remains potential rather than realised.

Innovation and Entrepreneurship Benefits

The innovation and entrepreneurship benefit lies in GeoAndina's development of an internal **capability to integrate InSAR into engineering services** across planning, design, operation and maintenance. This allows the company to offer more advanced monitoring and decision-support services, **differentiates it in a relatively immature Colombian market** and strengthens its position as an **early adopter** and specialist integrator. The company has financed this capability internally and has actively promoted the wider use of EO since 2014–2015.

Science and Technology Benefits

GeoAndina also contributes to science and technology through the operational integration and diffusion of InSAR-based monitoring practice. It has published applied work on remote sensing and instrumentation monitoring for Colombian infrastructure, including linear-infrastructure settings.[36] This contribution relates to the company's wider professional and research activity rather than to new scientific output produced specifically by this case.

Societal Benefits

A benefit that is realised here but largely passed downstream: by reducing uncertainty and supporting more preventive management of terrain-related risk, GeoAndina's use of InSAR contributes to the reliability and safety of infrastructure on which society depends. The use of external, objective satellite data also improves the credibility and transparency of its recommendations to clients; the competitive dimension of this positioning is treated as the innovation benefit above.

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[35] INVÍAS (2025). Manual de Estabilidad de Taludes, 2025 update (draft under consultation), and Manual de Diseño Geométrico de Carreteras, 2025 update, which incorporates the corredor geotécnico concept. Instituto Nacional de Vías, Colombia. https://es.scribd.com/document/837688094/MDG-2025-V3

[36] Salazar, H. A., & Restrepo, V. H. (2020). Remote sensing monitoring applications for landslides in infrastructure projects in Colombia. *SCG-XIII International Symposium on Landslides*, Cartagena, Colombia, 15–19 June 2020.https://www.issmge.org/uploads/publications/105/106/ISL2020-145.pdf; Restrepo, V., Salazar, H., & Piedrahita, J. (2023). Automated geotechnical instrumentation and monitoring for linear projects: Application examples in Colombia. Grupo *GeoAndina*, IPG2023-0010. https://www.capacitacion.aciem.com.co/IPG_2023/Trabajos/IPG2023-0010_TRA_COL_V_RESTREPO.pdf

5.2.3 The transmission asset owner (Tier 3) – Enlaza / Grupo Energía Bogotá

Counterfactual. Without early deformation warning, terrain-driven damage on a monitored sector would be addressed reactively, after visible damage or failure, rather than converted into a planned intervention.

Economic Benefits

The mechanism at Tier 3 is the **protection of asset value**. Continuous monitoring helps GEB to avoid a major terrain-driven failure or to convert it into a planned and less costly intervention. The indicator is the economic exposure that such a failure represents, sized in two complementary ways: an anchor for the scale of value at stake, and a probability-weighted estimate of the benefit in an average year.

The exposure anchor. A single major event on a comparable line is on the order of several million euros. A transmission-line geotechnical specialist reported individual events on the Colombian network exceeding COP 15,000 million, approximately **€3.8 million**, while a peer-reviewed study of a landslide-affected tower on the ultra-high-voltage Sichuan–Shanghai transmission line in China records a realised event cost of around **€6 million**, combining reconstruction and indirect losses. Both figures are lower bounds, because the full consequence extend beyond unsupplied energy to emergency response, slope stabilisation, reconstruction, temporary bypass works, contractual penalties, reputational cost and lost revenue. In an extended outage the supply-loss component alone can be considerably larger: the same study reports an avoided electricity-supply loss on the order of **€35 million over a 100-day outage**.[37] This anchor measures the scale at stake, not a probability-weighted avoided cost.

The unit cost of an outage. Where an outage does leave demand unserved, the appropriate price is the regulated cost of rationing rather than the retail tariff. Colombia's Costo Incremental Operativo de Racionamiento (CRO), which serves as the regulatory ceiling under CREG Resolución 101 042 de 2024, ranges from approximately **€476/MWh** at the first rationing segment to approximately **€3,886/MWh** at the deepest.[38] In practice a lost line is usually rerouted under N-1 security, so the routine cost is a regulated unavailability penalty; the CRO applies only in the exceptional case where demand is actually curtailed. These are unit costs rather than benefits. They enter the estimate in Annex 2 only to price the indirect component of

[37] Huang, C., Yin, K., Liang, X., et al. (2024). Study of direct and indirect risk assessment of landslide impacts on ultra-high-voltage electricity transmission lines. *Scientific Reports, 14*, 25719. https://www.nature.com/articles/s41598-024-76726-x

[38] UPME, Costo Incremental Operativo de Racionamiento (CRO), June 2026 (pesos of 31 May 2026), EUR 1 ≈ COP 3,950; CREG Resolución 101 042 de 2024. https://www.upme.gov.co/simec/oferta-y-demanda/costo-incremental-operativo-de-racionamiento-cro/

an outage, once its duration and unserved load are specified, and they are not applied to the headline figures directly.

Expected annual benefit. The anchor sizes a single event but does not indicate how frequently a failure occurs, nor how much of its cost monitoring removes. To capture this, the consequence of a failure is weighted by its annual probability and by the share that early satellite warning can realistically avoid, summed across the monitored sectors:

Expected avoided loss / year = N_sectors × P_event × Consequence × Attribution

The four terms are as follows:

- **Monitored sectors (N_sectors): four.** The four critical sectors currently under continuous monitoring. Six further sectors are planned; the effect of extending to all ten is given below.
- **Occurrence (P_event): 1–3% per sector per year.** The specialist judged this range conservative for genuinely critical sites. The 36–42% conditional probability for a tower already on an active landslide sits well above, so it is not used directly.
- **Consequence: approximately €3–10 million per event.** This combines the direct rebuild cost of the lost towers, at €1.1–1.9 million per tower for one to three towers, with an indirect cost that depends on how the network responds. Where the line can reroute under N-1 security – the requirement to withstand the loss of any single element – the indirect cost is the regulated unavailability penalty, assumed here at €1.5–4 million. Only where the network cannot reroute does the cost of unsupplied energy arise, priced at the CRO. The penalty range is an assumption.
- **Attribution: 20%, with a more favourable 50% case.** The 20% follows the Italian highways case, in which planners claimed only a fifth of the avoidable cost on the grounds that InSAR is one input among several and that not every event produces an actionable signal in time.[39] The 50% upper case reflects the more favourable situations, where the metallic towers act as strong reflectors and a clear, sustained deformation trend makes the warning reliably actionable.

For the four sectors currently under continuous monitoring, this yields an expected benefit of approximately **€24,000 per year at the conservative end and €240,000 at the upper end.** Both ends use the 20% attribution assumption; the more favourable 50% case is set out in A2.3 and is not carried into the headline figures. Extending monitoring to the ten planned sectors scales

[39] EARSC / Evenflow (2022). Highways Management in Italy, Sentinel Benefits Study (SeBS-CR-002).

the range to roughly €60,000–600,000 a year on the same attribution basis. The full parameter, scenario and result tables are provided in A2.3.

The attribution at this tier is **partial and contributory**: InSAR-derived information is one input into GEB's risk management, not a guarantee against failure. Because GEB is, to a substantial degree, publicly owned, the protection of this asset value also carries a public-investment dimension.

Regulatory Benefits

A regulatory dimension attaches to the same mechanism. The unavailability and unsupplied-energy charges that monitoring helps GEB avoid are **regulated instruments**, set by CREG rather than commercially negotiated, so their avoidance carries a regulatory character as well as an economic one.

Environmental Benefits

The direct environmental benefit at this tier is low, but there is one potential benefit worth considering, and it comes through the same mechanism as the economic benefit. Sentinel-derived screening identifies a deforming sector; this can help avert, or enable a planned intervention before, a terrain-driven failure. And, in jurisdictions where power-line ignition is a documented hazard, an averted failure is also an averted ignition source: ground movement that destabilises a foundation, distorts a structure, or alters conductor sag and clearance can create the conditions in which a line starts a fire, through arcing, conductor contact or collapse. The Colombian dry season can produce conditions under which that pathway would matter. For instance, in January 2024, during El Niño, more than 440 wildfires were recorded nationally, the government declared a state of disaster and public calamity on 25 January.[40] This pathway is plausible but unverified for the monitored corridors: no evidence has been identified that fire is a documented hazard on these specific lines, and no environmental benefit is therefore treated as realised or quantified.

5.2.4 Citizens and society (Tier 4)

Counterfactual. Without the upstream screening, the likelihood and duration of terrain-driven interruptions would be higher by whatever monitoring removes at Tier 3. No separate counterfactual is priced at this tier, to avoid double-counting.

[40] ACAPS (2024). *Colombia: Anticipatory Impact of Wildfires*. Briefing note, 20 February 2024. https://www.acaps.org/fileadmin/Data_Product/Main_media/20240220_ACAPS_briefing_note_wildfires_in_Colombia.pdf

Societal Benefits

The benefit at Tier 4 is the avoidance of disruption to electricity supply and the wider economic and social costs that a major transmission failure imposes on households, public services and economic activity.[41] The mechanism is indirect: better-targeted monitoring upstream reduces the likelihood and duration of terrain-related outages, and the value of that improvement accrues to society. This benefit is therefore associated primarily with avoided disruption and is not separately monetised here, both because the underlying failure-frequency data are not available and to avoid double-counting the exposure already discussed at Tier 3.

Environmental Benefits

The environmental value at this tier is indirect and follows the same logic as the societal benefit. A further effect is the **avoided-ignition** pathway introduced at Tier 3: a wildfire started by a terrain-driven line failure would impose costs on health, air quality and ecosystems well beyond the asset, and in the Colombian dry-season context the consequences could be significant, although the pathway has not been documented for the monitored corridors.

5.2.5 Other beneficiaries

Several actors outside the core four-tier value chain have an interest in the service, although only some can currently be identified as beneficiaries.

The Capital District of Bogotá is the clearest additional beneficiary. It holds a controlling stake in Grupo Energía Bogotá, meaning that a substantial share of the infrastructure value protected through improved monitoring is publicly owned. Reducing the risk of avoidable damage, operational disruption and associated financial loss therefore also protects public investment. This benefit is not additional to the Tier 3 asset-protection benefit and should not be monetised separately, but it gives that benefit a public-finance dimension.

XM and the National Dispatch Centre (CND) may benefit indirectly from improved transmission reliability. As the organisation responsible for real-time operation of the interconnected electricity system, XM must manage the system-level consequences of transmission outages, including rerouting and operational balancing. Avoiding an unexpected terrain-driven failure may reduce the need for such responses. However, XM does not receive or

[41] World Bank (2019). *Lifelines: The Resilient Infrastructure Opportunity*. https://documents1.worldbank.org/curated/en/111181560974989791/pdf/Lifelines-The-Resilient-Infrastructure-Opportunity.pdf

use the Sentinel-derived information directly in this case, so the benefit is indirect and qualitative.

CREG and UPME are potential institutional beneficiaries. CREG establishes the regulatory mechanisms governing transmission unavailability and unsupplied energy, while UPME publishes the regulated cost of rationing. Operational evidence from this case could, in the future, inform national guidance, standards or procurement requirements for satellite-based infrastructure monitoring. This pathway remains potential, as neither organisation is currently documented as receiving the service outputs and GeoAndina's proposed guidance has not been formally adopted.

The case may also provide a demonstration benefit for **other Colombian transmission operators**. The publication of the Enlaza and GEB application provides a national reference showing how InSAR can support inspection prioritisation and more preventive management of terrain-related risks. However, no wider uptake attributable to this case has yet been documented.

5.3 Summary of the benefits

The pattern of benefits across the value chain is summarised below by dimension.

5.3.1 Economic

Quantified at Tier 1 (≈€320,000 a year in avoided commercial-data cost, ≈€500,000 cumulative), with high attribution to Sentinel. At **Tier 2**, the InSAR prioritisation that enables the field-inspection saving realised downstream, together with an indicative **corridor-planning saving of approximately €200,000** per major exercise (not annualised; reported in Table 1 and Annex 2 but not added to the total). At **Tier 3**, the avoided field-inspection cost (**≈€5,000–10,000 a year**, conservative case) and an expected avoided failure loss of roughly **€24,000–240,000 a year**, set against a single-event exposure anchor of several million euros per event, rising to tens of millions only in the extended-outage case discussed in §5.2.3; attribution partial and contributory. Taken together, the Tier 1 and Tier 3 estimates indicate an illustrative combined economic-benefit range of approximately **€350,000–570,000 per year** (Table 1). The Tier 1 estimate measures the avoided cost of commercial imagery while holding the service specification constant, whereas the Tier 3 estimates measure avoided inspection costs and expected losses relative to a situation without equivalent satellite screening. The combined range is therefore an indicative order of magnitude rather than a strictly additive or audited total.

Table 1: Summarised Economic benefits by Tiers

Tier	Actor	Economic benefit (per year unless noted)	Status and attribution
Tier 1	Detektia	**≈€320,000** avoided commercial-data cost (≈€500,000 cumulative)	Quantified; high attribution – cost exists only if free data is removed
Tier 2	GeoAndina	Corridor-planning saving ≈€200,000 per major exercise (indicative; not annualised; not in total); enables the Tier-3 field-inspection saving	Estimated; reported for completeness, not aggregated
Tier 3	Enlaza / GEB	Avoided field inspections **≈€5,000–10,000** + expected avoided failure loss **≈€24,000–240,000**; exposure anchor of several million € per event	Estimated; partial, contributory attribution
Tier 4	Citizens / society	Avoided disruption to supply – not separately monetised	Qualitative; avoids double-counting Tier 3
Illustrative headline total		**≈€350,000–570,000 / year**	Tier-1 figure plus the Tier-3 estimates (which include the field-inspection saving generated by the Tier-2 mechanism); excludes the Tier-2 corridor-planning saving and the exposure anchor; not audited

Figures are reported in a hierarchy of robustness; items shown for completeness but excluded from the headline total are set out in Annex 2.



- **Tier 1:** ≈€320,000/yr avoided commercial-data cost (≈€500k cumulative)
- **Tier 2:** ~€200,000/yr design-efficiency saving (indicative)
- **Tier 3:** €5,000–10,000/yr avoided inspections + €24,000–240,000/yr expected failure-loss avoidance; single-event exposure in the tens of millions
- Headline total ≈ €350,000–570,000/yr

5.3.2 Environmental

Environmental benefit is assessed as low overall but not negligible, and – unlike the other dimensions – it is concentrated in a single, indirect pathway rather than distributed across the tiers. Ground-deformation monitoring of a transmission corridor produces no direct environmental output of material weight; its one environmental channel is contingent. A transmission line is a recognised ignition source, so a terrain-driven failure averted by monitoring is also, potentially, a wildfire averted, and in the Colombian Andean dry season – whose 2024 fire activity around Bogotá is recent and documented – that pathway would, if present on these corridors, be the most consequential environmental effect in the chain. It is identified rather than quantified: there is no evidence that fire is a documented hazard on the monitored lines, and neither Detektia nor the asset owner frames the service in these terms. Rainfall-dominant triggering points the same way: since terrain-driven failures on these corridors are most likely

during heavy rainfall, the coincidence of a failure with dry, fire-prone conditions is correspondingly less likely, further limiting the weight this pathway can carry.



- Potential avoided-wildfire-ignition pathway from preventing terrain-driven line failures (Tier 3–4)

5.3.3 Regulatory

The regulatory dimension is realised at Tier 3, potential at Tier 2, and not claimed at Tier 1. At the asset-owner tier it is a property of the economic mechanism, not a separate benefit: the unavailability and unsupplied-energy charges that monitoring helps avoid are instruments set by the regulator (CREG), not commercially negotiated terms, so their avoidance carries a regulatory character alongside its economic value – though nothing is claimed beyond the value already counted. At the primary-user tier the benefit is potential and unrealised: GeoAndina has promoted the integration of Earth-observation monitoring into Colombian infrastructure practice since 2014–2015 and has proposed guidelines for it, and INVÍAS's 2025 manual updates now incorporate InSAR and the corredor geotécnico concept, but neither GeoAndina's proposals nor the INVÍAS drafts are yet binding standards. The dimension therefore rests on a documented but unrealised route to standard-setting, not on a binding rule of the kind that would anchor it in a compliance-driven case. A further mechanism concerns *force majeure*: the Colombian transmission framework contains explicit carve-outs, with unavailability-related costs assigned to the responsible transporter except where the unavailability originates in events constituting *fuerza mayor* or *caso fortuito*.[42] This makes the evidentiary role of monitoring potentially consequential: objective deformation records could in principle inform whether a terrain-driven failure qualifies as such an event, evidence that could support or undermine a force majeure claim depending on whether prior warning existed. No instance of such use is documented in this case.



- Tier 2: promotion of monitoring standards (potential).
- Tier 3: avoidance of regulated CREG penalties – a regulatory mechanism counted economically

[42] CREG (1996). Resolución CREG 099 de 1996, Article 50, as compiled in the CREG regulatory compendium (Art. 2.2.2.1.2.7.4). https://gestornormativo.creg.gov.co/gestor/entorno/docs/ee_2_2_2_1_2_7.htm

5.3.4 Innovation and entrepreneurship

Innovation and entrepreneurship are the strongest non-economic dimension, concentrated at the two upstream tiers. At Tier 1 it is foundational: free and open Sentinel-1 data lowered the cost of market entry enough for a five-person university spin-off to become commercially viable, sustaining highly skilled jobs and producing award-recognised algorithm development (the 2024 Cassini Challenge) and Horizon Europe participation. At Tier 2 it is a shift in professional practice: InSAR supports GeoAndina's movement from reactive investigation towards more continuous and preventive infrastructure management and strengthens its positioning as an early adopter and market educator in a Colombian EO market it describes as still immature. Both actors are private-sector specialists rather than public institutions – the profile most often associated with the higher innovation grades across SeBS cases.

- **Tier 1:** Sentinel-enabled emergence of Detektia as a viable company – five skilled jobs and award-winning algorithm development (2024 Cassini Challenge).
- **Tier 2:** GeoAndina's shift from reactive to predictive infrastructure management – early adopter and market educator.

5.3.5 Science and technology

The science and technology contribution is moderate and spread across the two upstream tiers, though it is general to the actors rather than specific to this corridor. At Tier 1, Detektia has contributed to peer-reviewed work on InSAR applications – in port and structural-health monitoring, and as co-author on dam-related studies – and runs an online training course, the InSAR Academy, which it intends to widen through the ESA Network of Resources; none of that published work concerns the Colombian powerline case directly. At Tier 2, GeoAndina has itself published on remote-sensing and instrumentation monitoring for Colombian infrastructure, contributing applied methodological knowledge in exactly the linear-infrastructure setting this case examines[43]. The dimension is real but modest: it reflects the diffusion of monitoring practice by both actors more than any new scientific output tied to these specific transmission lines.

The use of the technology has helped the primary user improve its own understanding of the challenge; GeoAndina reports that wide-area deformation screening changed how it reads

[43] Salazar, H. A., & Restrepo, V. H. (2020). Remote sensing monitoring applications for landslides in infrastructure projects in Colombia. *SCG-XIII International Symposium on Landslides*, Cartagena, Colombia, 15–19 June 2020.https://www.issmge.org/uploads/publications/105/106/ISL2020-145.pdf; Restrepo, V., Salazar, H., & Piedrahita, J. (2023). *Automated geotechnical instrumentation and monitoring for linear projects: Application examples in Colombia*. Grupo GeoAndina, IPG2023-0010. https://www.capacitacion.aciem.com.co/IPG_2023/Trabajos/IPG2023-0010_TRA_COL_V_RESTREPO.pdf

terrain behaviour along corridors – from point observations towards continuous spatial and temporal baselines – a shift that underpins its move towards more preventive practice (Section 5.3.4).



- **Tier 1:** contribution to InSAR practice through peer-reviewed publications and the InSAR Academy
- **Tier 2:** applied publications on remote-sensing monitoring for Colombian linear infrastructure

5.3.6 Societal

The societal benefit is evident but largely indirect, and it is realised furthest downstream. Better-targeted monitoring at Tiers 2 and 3 reduces the likelihood and duration of terrain-driven interruptions to a transmission network on which the great majority of Colombians depend, so the value reaches households, public services and economic activity as avoided disruption rather than as an invoiced saving. A more immediate thread runs through Tier 2, where reliance on objective, external satellite evidence improves the credibility and transparency of the recommendations GeoAndina makes to the asset owner. Because GEB is substantially publicly owned, part of the asset value protected also represents public investment. This is not an additional societal benefit, but it gives the Tier 3 avoided loss a public-finance dimension.



- **Tier 4:** reliable electricity supply and public safety for the population and economy that depend on the grid
- **Tier 2:** more preventive risk management supports infrastructure reliability; objective satellite data improves the credibility of recommendations

6 Key findings and Final Thoughts

6.1 Key findings

The wide availability and frequent coverage of Sentinel-1 SAR data is enabling a chain of practical value in the management of power transmission infrastructure in Colombia. Freely available radar data, processed into interpretable ground-deformation information by a specialised service provider, is used by a geotechnical engineering group to screen long transmission corridors, prioritise where engineering attention is directed, and support more preventive management of terrain-related risk for the asset owner.

The central finding concerns where value is created. Sentinel-1 data have limited operational value in isolation; their value is realised when repeated radar observations are processed into decision-support information and interpreted through professional engineering judgement. Each link in this chain is necessary, and the resulting **benefits accrue across the value chain** rather than at a single point.

The economic evidence is strongest and most specific at the service-provider level, where free Sentinel-1 data displaces **commercial radar data** that would otherwise cost on the order of **€320,000 per year** for this contract. Downstream, the benefits are estimated: an indicative saving of approximately €200,000 per major corridor-planning exercise at Tier 2, and, at Tier 3, €5,000–10,000 a year in avoided field inspections together with a probability-weighted €24,000–240,000 a year in averted failure exposure. The underlying benefit mechanisms are well supported, but the magnitudes remain indicative because they rely on external benchmarks and stated assumptions. Beyond the economic dimension, the most significant benefit is to innovation and entrepreneurship, both in the very existence of Detektia as a Sentinel-enabled company and in GeoAndina's movement towards more continuous and preventive infrastructure management. Environmental benefits are limited but potentially consequential, particularly where avoiding a terrain-driven line failure could also prevent wildfire ignition and its wider impacts on ecosystems, health and air quality.

6.2 The impact of Sentinel data

Sentinel data have a decisive impact on this case in three respects.

First, it is enabling at the level of the service provider. Detektia states that without free and open Copernicus data the company would probably not exist, and that around 90–95% of the data it uses comes from Sentinel-1. The free-data policy lowered the entry cost enough for a small, research-derived company to become commercially viable, and it is the absence of recurring commercial-data costs that allows the company to operate. This is the clearest possible illustration of the enabling effect of the open-data policy on the downstream EO sector.

Second, it is the foundation of the operational service. The wide-area, repeatable coverage of Sentinel-1 is what makes it possible to screen 2,500 to 3,000 kilometres of corridor and concentrate attention on the ten critical sectors, and ultimately on the four areas under continuous monitoring. The ten-sector count reflects GeoAndina's geotechnical criticality assessment of the network rather than a limit of the monitoring technique: Sentinel-1 coverage would permit screening additional corridor sections, and the contract already envisages extending continuous monitoring from four to the ten identified sectors (Sections 5.2.3 and 7.3).

The deep historical archive allows engineers to establish whether a recent movement is a new anomaly or part of a longer-term trend, an objective baseline that conventional methods cannot provide. For power-transmission infrastructure, metallic towers can provide useful radar reflectors and controlled vegetation around some tower sites can partially mitigate vegetation-decorrelation limitations. Detectability nevertheless remains dependent on local conditions and the availability of reliable measurement points.

Third, the ability to measure millimetre-per-year ground movement consistently across thousands of measurement points, regardless of cloud cover or daylight conditions, is what allows the service to support engineering decisions in a country where intense rainfall and persistent cloud cover would constrain the consistent use of optical methods. The value in this case does not necessarily require the higher spatial resolution of commercial missions; identifying whether ground movement is occurring and locating the affected area with sufficient precision can support the screening and prioritisation required by the service.

6.3 Interpretation of results: key assumptions and limitations

The interpretation of these results rests on a set of **explicit methodological choices**, and the level of confidence associated with them **varies across the value chain**. This section sets out the key assumptions underpinning the results, assesses the strength of the supporting evidence and defines the limits within which the findings should be interpreted, so that they can be incorporated into the thematic benchmark reports with the appropriate caveats.

The **largest source of uncertainty is the absence of operational records from the primary and secondary users**. Visit-level inspection records, the historical frequency of geotechnical events along the monitored corridors and contract values between the Tiers were therefore **estimated using external benchmarks and stakeholder judgement rather than measured operational data**. GeoAndina does not hold the relevant field records, as the inspections are carried out directly by the asset owner. The project team was also **unable to obtain these data** from Enlaza or GEB.

The counterfactuals stated at each Tier are not supported with the same level of confidence. At Tier 1, the counterfactual is relatively well supported: the service is operational, the commercial

replacement data can be identified and priced, and the resulting avoided imagery cost can therefore be estimated directly. At Tier 2, the counterfactual is more assumption-dependent because no Colombian or transmission-specific standard prescribes a particular inspection frequency. The assumed baseline of one to two inspection campaigns per year is therefore a transferred proxy considered plausible by the primary user, rather than a documented operational practice. At Tier 3, the counterfactual is subject to the greatest uncertainty, as it requires assumptions about both the frequency of terrain-related events and the proportion for which early warning would enable planned rather than reactive intervention.

The evidence supporting the quantified results also varies considerably and, in some cases, is narrower than the numerical precision may suggest. The Tier 1 estimate of approximately **€320,000 per year is the most robust figure**, as both the unit rate and the assumed cadence of eight updates per year were confirmed in writing by the organisation that generated the estimate.

The estimated **€5,000–€10,000 field-inspection saving** is well supported in terms of its underlying mechanism but remains indicative in magnitude. The assumed 50% reduction in inspection effort, the frequency of inspection campaigns and the mode of access were considered plausible by the primary user, although that organisation does not itself undertake the field campaigns.

The indicative €200,000 corridor-planning **saving per major exercise** is based on a **single order-of-magnitude estimate** provided during an interview. The available evidence does not establish the frequency of such exercises or the proportion attributable specifically to Sentinel-1. It is therefore not annualised and is reported separately from the combined range. The estimated **€24,000–€240,000 expected avoided loss** is a probability-weighted calculation whose least certain input – the assumed annual event probability of 1–3% – is based on one expert judgement rather than a documented history of events along the monitored corridors.

Except for the relatively robust Tier 1 estimate, these figures should therefore be interpreted as **order-of-magnitude indications rather than audited amounts**. Furthermore, t**hree benchmarks are transferred from other contexts, and it is important to clarify both how they are used and what is not inferred from them.**

Duan et al. report a 60% reduction in monitoring costs for highway slopes in Bijie, China. In the present analysis, a more conservative lower bound of 50% is adopted and applied to inspection effort rather than total monitoring cost. This is treated as a proxy, not as a direct equivalence.[44]

[44] Duan, L., Lim, H. S., Mohd Sharoni, S. M. H., Chen, M., et al. (2025). Assessing highway slope stability risks using InSAR: a case study in Bijie, China. *Geocarto International, 40*(1), 2521661. https://doi.org/10.1080/10106049.2025.2521661

Huang et al. examine ultra-high-voltage transmission lines in China. It is used only to indicate the potential scale of losses associated with a major failure and is not used to derive a probability-weighted avoided-cost estimate.[45]

The **Network Rail earthworks hazard categories**, reported by Maleki et al., originate from a United Kingdom rail standard. They are used here as a minimum reference for inspection cadence because no equivalent Colombian or transmission-specific standard was identified.[46]

Published failure rates for 500 kV overhead transmission lines were also considered but were not used in the analysis. The available figures relate to a stable-terrain European network, include failures from all causes, not only terrain-related events, and are expressed per 100 kilometres of line instead of per monitored sector. As the lengths of the monitored sectors are not known, these figures cannot be converted into a comparable annual event probability.[47]

Across all three benchmarks, the analysis does not assume that InSAR predicts infrastructure failure. **InSAR detects and measures ground deformation**; it provides **evidence** that can support screening, prioritisation and early investigation.

The environmental finding describes a **plausible but contingent pathway rather than an observed or measured effect**. Power-line failure is a documented wildfire ignition mechanism in other jurisdictions, where component failure or contact between conductors and foreign objects can cause arcing or eject hot material.[48] The Colombian dry season can produce the conditions in which such an ignition could have significant consequences.[49] But there is **no evidence that fire is a documented hazard on the monitored corridors**, and neither the service provider nor the asset owner frames the service in these terms. The finding is **firm as the identification of a pathway** and carries **no quantified value**.

The applicability of the detection layer is constrained by physical conditions and should be interpreted only in relation to corridors that meet them. C-band radar can lose coherence over dense vegetation, while steep terrain can introduce geometric distortion through

[45] Huang, C., Yin, K., Liang, X., et al. (2024). Study of direct and indirect risk assessment of landslide impacts on ultra-high-voltage electricity transmission lines. *Scientific Reports, 14*, 25719. https://www.nature.com/articles/s41598-024-76726-x

[46] Maleki, Z. R., et al. (2025). Geophysical survey and monitoring of transportation infrastructure slopes (TISs): A review. Geosciences, 15, 220. https://doi.org/10.3390/geosciences15060220

[47] Galiaskarov, I., Misrikhanov, M., Ryabchenko, V., & Shuntov, A. (2023). Accident analysis of 220, 500 kV overhead lines of the main power systems network. E3S Web of Conferences, 461, 01011 (RSES 2023). https://doi.org/10.1051/e3sconf/202346101011

[48] Mitchell, J. W. (2013). Power line failures and catastrophic wildfires under extreme weather conditions. *Engineering Failure Analysis, 35*, 726–735. https://doi.org/10.1016/j.engfailanal.2013.07.006

[49] ACAPS (2024). *Colombia: Anticipatory Impact of Wildfires*. Briefing note, 20 February 2024. https://www.acaps.org/fileadmin/Data_Product/Main_media/20240220_ACAPS_briefing_note_wildfires_in_Colombia.pdf

foreshortening, layover and radar shadow. Both are well-documented limitations of satellite interferometry in mountainous environments.[50] **Two characteristics of this application help mitigate these constraints:** lattice-steel towers provide strong radar reflectors, and vegetation around the tower sites is kept under control. Other limitations remain. Only one viewing geometry is available over part of the monitored area. According to the asset owner, this **reduces the precision** with which the magnitude of movement can be characterised, although zones of accumulating deformation can still be identified. This is a general limitation of satellite geometry rather than one specific to this case: **radar shadow and layover may make terrain visible from one viewing direction** but not another, while characterising movement in three dimensions requires multiple geometries that are not available throughout the monitored area.[50]

In addition, the transmission-line specialist consulted for the study noted that **InSAR is less reliable for detecting slow structural deformation of lattice-steel towers** themselves. The findings should therefore be understood as applying primarily to the detection of ground movement along metallic-tower corridors with **controlled vegetation and adequate viewing geometry**, rather than to all forms of linear infrastructure or structural deformation.

Five of the six benefit dimensions are assessed qualitatively. Only the economic dimension is quantified against an explicit counterfactual. The environmental, regulatory, innovation, science and technology, and societal findings are evidence-informed qualitative assessments, supported by stakeholder interviews and publicly available evidence rather than measured outcomes.

Among these dimensions, the **innovation finding has the strongest evidential basis**, as it rests on documented company activities and outputs. The causal mechanism underlying the regulatory finding is also well supported, because the unavailability and unsupplied-energy mechanisms on which it depends are established through binding regulation issued by CREG. The science and technology and societal findings are highly specific to the circumstances of this case and should not be generalised or transferred to other contexts without additional supporting evidence. The environmental finding has the weakest evidential basis, for the reasons set out above.

Sentinel-1 mission continuity is assumed, and that assumption is not abstract for this case. **Sentinel-1B ceased providing data in December 2021** following a power anomaly, ending the paired configuration that had **reduced revisit from twelve days to six**. [50] The results assume **dual-satellite coverage is maintained**; a return to single-satellite operation would degrade the update cadence and could **reduce the availability of complementary viewing geometries** on

[50] Cheng, Y., Pang, H., Li, Y., Fan, L., Wei, S., Yuan, Z., & Fang, Y. (2025). Applications and Advancements of Spaceborne InSAR in Landslide Monitoring and Susceptibility Mapping: A Systematic Review. Remote Sensing, 17(6), 999. https://doi.org/10.3390/rs17060999

which the Tier 2 and Tier 3 estimates depend. The single-geometry limitation already recorded over part of the monitored area illustrates the practical consequences of reduced viewing-geometry availability, whatever its cause.

Taken together, these points define the **limits of applicability of the case findings**. The results concern a single service chain across four monitored sectors of one asset owner's network. The service operates in Andean transmission corridors where metallic towers act as strong radar reflectors and vegetation around them is controlled, and it depends on the free and open Sentinel-1 C-band archive. Within that envelope, the Tier 1 avoided data cost is firm and stakeholder-confirmed; the downstream economic figures are well grounded in their underlying mechanisms but indicative in magnitude and draw on a combination of benchmarks transferred from other settings and stakeholder or expert judgement; and the non-economic dimensions are evidence-informed, case-specific judgements. It is this delineation, rather than any single headline figure, that should govern how the results are applied or transferred to future studies, benchmark reports or impact assessments.

6.4 Final thoughts

This case provides a clear and well-bounded illustration of how **freely available Sentinel data**, when processed and interpreted by capable downstream actors, **generate value** that extends from a small specialist company, through a national engineering group, to a major, partly publicly owned infrastructure asset and, ultimately, to the citizens who depend on it. The enabling effect of the open-data policy is particularly evident in this case, as the service provider states that the service would not exist without free and open Sentinel data.

A distinctive feature of the value chain is where the benefits ultimately accrue. Publicly funded European data, processed by a five-person company, contribute to protecting a transmission asset that is itself substantially publicly owned, thereby linking public investment in Earth observation data to the protection of public infrastructure and, ultimately, to benefits for citizens. The case also **illustrates a model enabled by a small and medium-sized enterprise (SME)**: a national-scale monitoring capability relies on a small, research-derived provider rather than a large incumbent. This demonstrates both the efficiency of the arrangement and its potential vulnerability.

The case is also at an early but expanding stage. The service has been operational with GeoAndina only **since 2024**, the contract envisages extending continuous monitoring from four to ten critical sectors, and the primary user is moving from reactive investigation towards more continuous and preventive management. If this expansion takes place, the benefits may increase, although the scale of that increase will depend on the risk profile, monitoring effectiveness and consequences of failure in the additional sectors.

Two developments could further increase these benefits. Next-generation missions such as the **L-band ROSE-L could** reduce the vegetation-related limitations affecting C-band InSAR in these

corridors. Analytical layers such as **Detektia's MoMo** could also extend the service from measuring deformation towards supporting its interpretation. Important questions for future SeBS360 work are whether InSAR-based monitoring becomes formally embedded in Colombian infrastructure standards and procurement practices, as has begun to occur in other European infrastructure-monitoring contexts, and whether the value scales as the approach expands from a limited number of critical sectors towards network-wide coverage.

6.5 How does this case relate to others

This case sits within a family of SeBS analyses of InSAR-based ground-motion monitoring and is most usefully considered alongside four related cases.

The closest analogue is the SeBS case on highways management in Italy (Planetek to ANAS). Both involve a commercial SME service provider, a single dominant primary user, the use of free Sentinel-1 data as a wide-area screening layer ahead of targeted action, and a benefit structure organised by lifecycle phase. The Italian case is also a relevant SeBS precedent for the measurement-based, non-predictive framing of InSAR adopted in this report. Citing the JPL analysis of the Morandi Bridge, it concludes that InSAR can detect signs of deformation but does not, on its own, predict structural failure. Its worked Tier 2 economic models cover reduced survey costs and reduced remedial-work costs; for the latter, the report applies a conservative attribution of 20% to the use of InSAR. These provide the closest methodological template for the GeoAndina Tier in this case, should the necessary operational data become available.

The ground-motion monitoring case in Norway (NGU to the Norwegian Public Roads Administration) provides the six-dimension benefit framework used here and explicitly finds that the environmental benefit of road InSAR is low, based on reasoning very similar to that applied in the Italian case. It also illustrates attribution at the upper end – up to 100% where there is no practical alternative capable of providing comparable information.

The pipeline-monitoring case in the Netherlands (SkyGeo to Stedin and Oasen) is the clearest worked example of the economic logic of using Sentinel-1 as a screening layer, with Sentinel-1 used for low-cost, wide-area screening and commercial X-band data for high-resolution investigation of identified areas. It attributes around 30% of the value to Sentinel-1 and demonstrates a fully worked lifecycle-costing model for the deferral of asset replacement.

The motorway-maintenance case in Portugal (Spotlite to Egis and onward to IMT and the NorScut concession) is the closest structural parallel of the four. It is the only other case in the family in which an independent engineering consultancy sits between the InSAR service provider and the asset owner, using deformation information to guide inspections and maintenance decisions, precisely the role played by GeoAndina in this case. Whereas the Italian, Norwegian and Dutch cases connect the provider directly to the asset owner, Portugal and Colombia share

a four-Tier chain in which the interpretation layer is a separate commercial actor with its own benefit profile.

Read together, these cases place the Colombia attribution in context. The stated 50% attribution of service value to Sentinel-1 at Tier 1 is higher than the Netherlands estimate of approximately 30% but remains coherent and defensible. The Colombia service is 90–95% Sentinel-based by data volume, and the provider states that it could not operate without Sentinel-1, whereas the Netherlands case depends substantially on commercial high-resolution data. The range across these cases – from approximately 30% to as much as 100%, depending on the role of Sentinel-1 and the availability of alternative or complementary data sources – places the Colombia figure within the range observed across the comparison cases.

7 Widening the perspective

The preceding chapters set out the benefits this case generates. This chapter asks how far they extend beyond it: where they would transfer, what conditions govern their size, and what could enlarge or constrain them. The service and the benefits are treated separately throughout, because they do not travel together. The analysis distinguishes between the technical conditions under which the service can operate, and the additional conditions required for its benefits to arise.

7.1 Geographic extrapolation

The benefits documented here are **not specific to Colombia, but their magnitude is**. The mechanism that produces them, free wide-area radar screening that concentrates engineering effort where the ground is moving, applies wherever terrain instability threatens distributed infrastructure. What varies is how much value it releases, and that depends on **five conditions**: the **density** and value of the network at risk, the **severity** and type of ground movement, the **cost of the alternative** methods displaced by InSAR, the **reliability of optical observations**, which determine the strength of the radar advantage, and whether the detected movement can lead to **timely and practicable engineering action**.

Colombia combines several of these conditions, placing the potential benefits towards the **upper end of the achievable range**. Young, unstable mountains, very high rainfall and pronounced seismicity increase the exposure of infrastructure along these corridors, while the concentration of population and infrastructure in the Andean region increases the value at risk. Where access requires costly field or helicopter inspections, the avoided-cost benefit is correspondingly greater. Persistent cloud cover makes radar particularly important for consistent monitoring. The provider's own market experience reflects this: Detektia reports stronger demand in the Americas than in Europe, which it associates with the greater extent of terrain requiring monitoring. A drier, flatter or more sparsely built setting would show **the same benefit structure at a smaller scale**. The cascade transfers; its size does not.

The technical applicability of the service sets an outer boundary on where these benefits can arise. Three conditions are particularly important. First, C-band radar can lose coherence over dense vegetation, so corridors through closed canopy may return fewer reliable measurement points. Second, steep terrain introduces foreshortening, layover and radar shadow, meaning that ground visible from one viewing direction may not be visible from another. More complete characterisation of movement requires complementary viewing geometries that are not available everywhere, while full three-dimensional reconstruction generally requires additional independent observations. Third, the technique depends on the availability of suitable radar reflectors. This case partly mitigates the first and third constraints because

metallic towers can provide useful reflectors and vegetation around tower sites is controlled. It is less favourable in relation to the second condition, as part of the monitored area is covered by only one viewing geometry. Where vegetation, viewing geometry or target characteristics reduce the number or reliability of measurement points, the ability to prioritise inspections and preventive interventions is also reduced, and the associated inspection, design and avoided-failure benefits may be smaller.

That combination sets the transfer boundary. The results extrapolate to **metallic-tower corridors in mountainous terrain with managed vegetation at the asset**. The findings should **not be assumed to extrapolate** to **buried assets**, **timber** or **composite structures that scatter poorly**, or corridors through **unmanaged closed canopy**. In such settings, fewer reliable measurement points may reduce the ability to prioritise inspections and interventions, and the corresponding inspection, design and avoided-failure benefits may be smaller or may not arise. Where **L-band** data become routinely available, the vegetation-related constraint may be reduced, as discussed in Section 7.4.

Within Colombia itself, the same screening logic applies to other linear infrastructure now in planning or construction, including metro lines and rail corridors, and deformation monitoring of this kind is a natural input to the Building Information Modelling (BIM)- and digital-twin-based risk-management approaches being adopted for major infrastructure works in the country and the region.

The environmental benefit is the most geographically conditional of all six, and it does not travel automatically with the others. It rests on a specific pathway: monitoring may help avert a terrain-driven failure and thereby remove a potential wildfire ignition source. Power-line failure is an established ignition mechanism, whether through conductor contact and arcing or through fatigue failure of conductors, poles and crossarms, and the likelihood of both mechanisms increases with wind speed.[51] But the pathway only has value where **fire-prone conditions and vulnerable land cover coincide with the corridor**. In a **wet temperate** setting, the pathway is likely to be substantially **less significant**, regardless of how well the monitoring works. In **Mediterranean, Australian or western North American corridors**, it could become a considerably more **important benefit** within the chain. Parts of Colombia experience dry-season conditions in which this pathway could become relevant,[52] but there is no evidence that wildfire is a documented hazard along the monitored corridors. It is therefore identified as a potential pathway but is not quantified.

[51] Mitchell, J. W. (2013). Power line failures and catastrophic wildfires under extreme weather conditions. *Engineering Failure Analysis, 35*, 726–735. https://doi.org/10.1016/j.engfailanal.2013.07.006

[52] ACAPS (2024). *Colombia: Anticipatory Impact of Wildfires*. Briefing note, 20 February 2024. https://www.acaps.org/fileadmin/Data_Product/Main_media/20240220_ACAPS_briefing_note_wildfires_in_Colombia.pdf

7.2 Administrative and institutional perspective

Institutional conditions determine both whether some benefits arise and how widely they spread: whether they remain confined to a few early adopters or extend across a sector.

The regulatory benefit is the most conditional of the non-economic dimensions, and the condition is precise. It exists in this case because Colombian regulation prices unavailability and unsupplied energy: CREG sets the penalty regime and UPME publishes the regulated cost of rationing, so avoiding an outage avoids a defined, externally set charge rather than a negotiated commercial loss. That gives the avoided cost a regulatory character alongside its economic one. **In a jurisdiction with no equivalent instrument, the regulatory benefit would fall close to zero, although the underlying economic benefit of avoiding physical damage and disruption could remain**. The two dimensions are genuinely separable, and this is the clearest case in the chain where one transfers and the other does not. The condition is common in regulated transmission markets and rare outside them, so the expectation is firm where such instruments exist and should not be assumed otherwise.

A second institutional condition governs how widely the benefit spreads. The market for EO services is described by the primary user as **immature, with little public funding or institutional incentive**, and adoption resting largely on GeoAndina's own advocacy since 2014–2015. Early approaches to institutional actors such as INVÍAS and the Ministry of Technology did not translate into formal support at the time, and institutional uptake remains incipient rather than absent: INVÍAS's ongoing manual updates now incorporate InSAR and the corredor geotécnico concept (Section 5.2.2). For now, however, the benefit remains confined to those who have chosen to adopt. **The lever that would widen it is institutional, not technical.** Formal recognition of InSAR monitoring in national infrastructure norms and procurement could help move the approach from firm-level practice towards wider sectoral adoption. That is the path the Italian case took, where the primary user embedded InSAR as a tender requirement,[53] and it is the instructive contrast for Colombia: the benefits remain confined under advocacy-led adoption but could extend more widely where the approach is institutionally recognised and incorporated into procurement.

The societal benefit transfers on two conditions, and they are independent of each other. The first is network topology. Value reaches households and businesses as avoided disruption only where a single line's failure propagates beyond the asset, and infrastructure disruption is disproportionately costly where networks are concentrated and alternatives are thin.[54] On a

[53] EARSC / Evenflow (2022). *Highways Management in Italy*, Sentinel Benefits Study (SeBS-CR-002).
[54] World Bank (2019). *Lifelines: The Resilient Infrastructure Opportunity*. https://documents1.worldbank.org/curated/en/111181560974989791/pdf/Lifelines-The-Resilient-Infrastructure-Opportunity.pdf

densely meshed grid with ample redundancy, the same avoided failure may have little or no perceptible effect on end users, although economic benefits may still accrue to the asset owner. The second is ownership. Because the Capital District of Bogotá holds a controlling stake in **GEB**, the protection of Tier 3 asset value also has a **public-finance dimension**. This is not a separate benefit and should not be counted in addition to the Tier 3 benefit, but it means that part of the value protected is publicly owned. **This dimension would not apply in the same way to a privately owned network.**

7.3 Improved market and user uptake

Uptake determines whether the documented benefits remain confined to the four sectors currently under continuous monitoring or extend across the ten sectors already planned. If the additional sectors have broadly comparable risk profiles, monitoring effectiveness and consequences of failure, the Tier 3 expected benefit would be approximately two and a half times the current estimate (Section 5.2.3). The realised increase would nevertheless depend on the characteristics of each sector and may not be directly proportional to the number monitored.

The available signals support the potential for wider uptake. The primary user is shifting from reactive monitoring of known problem sites towards broader, more preventive analysis of whole corridors, which it considers more valuable, and states that, were the service withdrawn, it would switch providers rather than revert to traditional methods. **This indicates embedded demand: the operational benefit appears durable because the technique has become part of how the organisation works, rather than because of its relationship with a particular supplier.** The corresponding risk lies on the supply side. The benefits depend heavily on the continuity of Sentinel-1 observations. The single-satellite period following the loss of Sentinel-1B reduced revisit frequency and, according to the provider, removed one of the two viewing geometries used in Colombia. This illustrates how interruptions in data continuity can weaken monitoring timeliness and reliability and, consequently, the benefits derived from the service.

The innovation and entrepreneurship benefit should not be assumed to arise automatically in every market. Three conditions came together in this case. Free and open data lowered the cost of market entry sufficiently for a five-person university spin-off to achieve commercial viability. A downstream user existed with both the technical capacity to interpret the outputs and the willingness to adopt them. The two actors also connected through conferences and scientific publication rather than through an established procurement route. Without any one of these conditions, the benefit would be materially weaker or might not arise. Free data alone does not create a viable company where there is no adopter, while the presence of a potential adopter is insufficient where market-entry costs remain prohibitive.

The comparator cases illustrate the same structure and its variants. Only Portugal shares Colombia's four-Tier chain with a separate interpretation firm (Section 6.5). In Italy, Norway and The Netherlands, the value chain runs from the provider directly to the asset owner, with the interpretation capability located within the client. **The operational benefits can therefore transfer without an intermediary, but the distinct entrepreneurship benefit associated with GeoAndina is most likely to arise where the market can support a specialist interpretation firm.** This benefit should not be extrapolated on the basis of free data availability alone. It also depends on demand from an operational user, suitable technical capability and relationships that connect the data provider, interpreter and asset owner.

7.4 Technological evolution and future service development

Two technological developments could enlarge the benefits, rather than merely extend the service.

The first concerns the continuity and capability of the Sentinel radar missions. The case period included a single-satellite phase after the loss of Sentinel-1B, when longer revisit intervals and, according to the provider, the loss of one viewing geometry degraded the monitoring. **This demonstrates that the benefits depend on the continuity and frequency of observations.** The restored two-satellite constellation reduces this limitation.

The planned L-band ROSE-L mission could further enlarge the benefits. Its longer wavelength penetrates vegetation more effectively than Sentinel-1's C-band and is intended to complement Sentinel-1 for ground-motion and geohazard monitoring in vegetated terrain.[1] **In benefit terms, this could increase the share of the network where reliable monitoring is possible, extend inspection-prioritisation and avoided-failure benefits to additional corridors, and increase confidence in estimates currently qualified by vegetation-related limitations.** It may also relax the transfer boundary set out in Section 7.1 by bringing some canopy-affected corridors within the range of reliable monitoring.

The second concerns the analytical layer applied to the InSAR series. Detektia's MoMo service, made available for beta testing on the DestinE platform in 2026, combines InSAR-derived deformation time series with climate and environmental data and provides breakpoint-detection and correlation-analysis functions. It can therefore help users distinguish expected behaviour from changes that may warrant investigation and explore their possible environmental drivers. **In benefit terms, this could improve inspection targeting and support more preventive management, although the additional benefit remains prospective and unquantified.**

The science and technology benefit is less systematically transferable than the other dimensions because it depends on the practices of the participating organisations. It arises

here because both upstream actors publish: Detektia through peer-reviewed work on InSAR applications and its online InSAR Academy, and GeoAndina through applied studies of remote sensing and geotechnical instrumentation for Colombian linear infrastructure. Neither activity depends solely on this contract, and neither would follow automatically from deploying the same service elsewhere. The relevant condition is therefore the presence of actors with an established research and publication practice, rather than the presence of the technology alone. **Where the same service is deployed through a purely commercial provider and a client with no research or publication function, this benefit may not arise even if the operational and economic benefits remain. It should therefore be treated as conditional on the presence of research-active actors, rather than as an automatic consequence of service deployment.**

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Annex 2: General approach, methodology and economic model

A2.1 The SeBS360 approach

This case has been analysed within the Sentinel Benefits Observatory (SeBS360), which continues the methodology developed under the earlier Sentinel Benefits Study (SeBS).[55] For each case, a value chain is defined that begins with the service provider (Tier 1) and the primary user (Tier 2) and follows the value through subsequent tiers to citizens and society. Benefits are assessed against six dimensions, economic, environmental, regulatory, innovation and entrepreneurship, science and technology, and societal, and for each benefit the assessment identifies the stakeholder, the mechanism, the indicator or proxy, the evidence, and the attribution to Sentinel data.

A2.2 Economic model and assumptions

The economic assessment rests on a small set of named assumptions, applied conservatively and mapped onto the tiers as follows.

Tier 1 – Avoided commercial-data cost. Direct stakeholder input: **€10,000 per area update × 8 updates per year × 4 areas ≈ €320,000 per year**; approximately 50 updates to date ≈ **€500,000** cumulative. Attribution is high, as the cost exists only if free Sentinel-1 data is removed.

Assumption 1 – Field-inspection saving (Tier 2 mechanism, counted at Tier 3). A 50% reduction in inspection effort, adopted as a conservative working assumption informed by the 60% monitoring-cost reduction reported by Duan et al. in a highway-slope context, with the CIMGA paper confirming that the mechanism operates on this corridor[56] – applied to a counterfactual of **one to two campaigns per critical area each year** (Network Rail hazard-category cadence as a floor, validated as plausible by the primary user and by a transmission-line geotechnical specialist) at an access-dominated **cost of roughly €2,500 per vehicle campaign**. This gives an avoided field-inspection cost of **≈€5,000–10,000 per year**. Because GEB, not GeoAndina, runs the campaigns, the saving is counted once at Tier 3.[57]

[55] The previous Sentinel Benefits Study produced a foundational methodology for assessing the impacts and benefits of the Sentinels across industry, science and society. Available at: https://earsc.org/sebs/wp-content/uploads/2020/12/SeBS-Methodology-2020.pdf

[56] Rodríguez Pardo, J. A., & Upegui Pachón, J. S. (2025). Innovaciones en tecnología satelital: monitoreo de líneas de transmisión y mantenimiento predictivo con InSAR. CIMGA 2025, Cartagena de Indias, May 2025. Copy held by the authors.

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Assumption 2 – Corridor-planning saving (Tier 2). GeoAndina reported that, during the planning phase, using InSAR to identify optimal infrastructure corridors without extensive fieldwork can generate savings of "hundreds of thousands" of euros. Approximately €200,000 is retained as an illustrative lower-end estimate per major corridor-planning exercise. InSAR may also support more efficient design and reinforcement by reducing uncertainty, but this effect has not been separately quantified. The available evidence does not establish the frequency of major corridor-planning exercises or the proportion of the saving attributable specifically to Sentinel-1. Reported as an indicative figure and, per the note below, not added to the headline total.

Assumption 3 – Major-failure exposure anchor (Tier 3). Individual major events are on the order of several million euros (**≈€3.8M** reported by the specialist; **≈€6M** realised in the peer-reviewed Yanzi case), with the supply-loss component alone reaching **≈€35M** over a 100-day closure.[58]

Assumption 4 – Cost of unsupplied energy (Tier 3). The regulated cost of rationing (CRO), **≈€476/MWh (CRO1, stratum 4) to ≈€3,886/MWh (CRO4)**.[59]

Assumption 5 – Probability-weighted expected benefit (Tier 3). Expected avoided loss/year = N_sectors × P_event × Consequence × Attribution, with **P_event 1–3%** per sector, **consequence ≈€3–10M**, and **attribution 20% (floor) to 50%**, giving **≈€24,000–240,000 per year** for the four monitored sectors. Full parameters and sources are set out in A2.3.

Attribution. Tier 1 avoided-cost: high (the cost exists only without free data). Tier 1 value attribution: approximately 50%, kept distinct from the 100% enabling condition. Tier 2: the field-inspection saving is quantified and counted at the asset-owner tier where it is realised, and the corridor-planning saving is indicative. Tier 3: partial and contributory (InSAR is one input among several). The attribution spectrum across comparable SeBS cases (Netherlands ≈30%; Italy around 20% fractional to 100%; Norway up to 100%) places the Colombia figures within a coherent range.

Reported for completeness, not aggregated. The following are shown to illustrate scale and operational value but are excluded from the headline total, for the reasons given:

Item	Value	Rationale for exclusion
Tier 2 – corridor-planning saving	~€200,000 per major exercise	Rests on a single order-of-magnitude estimate from interview; the frequency of such exercises

[58] Huang, C. et al. (2024). Study of direct and indirect risk assessment of landslide impacts on ultra-high-voltage electricity transmission lines. Scientific Reports, 14, 25719. https://doi.org/10.1038/s41598-024-76726-x
[59] UPME (2026). Costo Incremental Operativo de Racionamiento (CRO), June 2026 (pesos of 31 May 2026), EUR 1 ≈ COP 3,950; regulatory basis CREG Resolución 101 042 de 2024.

		and the share attributable to Sentinel-1 are not established, so the figure is not annualised.
Tier 3 – single-event exposure anchor	several million € per event	A measure of the scale at stake per event, not an annual figure; the annual benefit is captured separately by the probability-weighted estimate.

A2.3 Probability-weighted estimate (Tier 3)

Section 5.2.3 presents the probability-weighted expected benefit at Tier 3 and its headline result; this annex sets out the full parameters, scenarios and calculation behind it. The estimate is **illustrative, not audited**: every parameter is drawn from external benchmarks or expert judgement, not from operational data specific to the Enlaza corridors. It is complementary to the exposure anchor – the anchor states the value protected in a single event, while this estimate states the expected saving in an average year, once the likelihood of an event is taken into account.

The calculation is a standard expected-loss structure, applied to each monitored critical sector and summed:

Expected avoided loss / year = N_sectors × P_event × Consequence × Attribution

where N_sectors is the number of critical sectors under continuous monitoring, P_event the annual probability of a damaging deformation event in a sector, Consequence the financial cost of such an event, and Attribution the share of that cost that monitoring removes by converting an unmanaged failure into a planned intervention. The consequence term is itself the sum of a direct and an indirect component:

Consequence = Direct rebuild + Indirect outage
Indirect outage = Power (kWh/day) × Outage duration (days) × Unit cost (€/kWh)

The parameters and their sources are set out below. The value of the structure is not the precision of any single figure, but that it makes each assumption explicit and open to replacement.

Parameter	Range used	Basis and source
P_event (annual, per sector)	**1–3%**	1–3%/yr for critical sites is conservative in Colombian practice (transmission-line geotechnical specialist, June 2026). Published all-cause overhead-line failure rates (Galiaskarov et al., 2023) are not comparable and are not used as a bracket. The 36–42% conditional probability for a tower on a known active landslide[58] sits well above and is not used directly.

Direct rebuild	€1.1–1.9M per tower; 1–3 towers per event	Tower reconstruction and relocation costs[58] (Yanzi case)
Outage duration	2–8 days (emergency bypass); weeks to months (permanent); up to 100 days (extreme)	Emergency restoration times (EPR Magazine; The Watchers, Malaysia 2025, illustrative); 100-day case[58]
Unit cost of unsupplied energy	**~€476–3,886/MWh**	UPME CRO (regulated cost of rationing), June 2026; or the CREG regulated unavailability penalty for the reroute case
Attribution	**~20% (floor), rising to 50%**	Conservative convention from the Italian highways case (SeBS-CR-002)

The consequence of an event depends on how the network responds. Under N-1 security a single line trip is usually rerouted, so the indirect cost is the regulated unavailability penalty rather than unsupplied energy, which arises only where the network cannot reroute the lost line. Blending the two cases gives a consequence of roughly **€3–10 million per event**:

Scenario	Towers lost	Direct rebuild	Outage regime	Indirect cost	Consequence (rounded)
Low	1	~€1.1M	Rerouted (N-1 holds)	~€1.5M penalty	**~€3M**
High	3	~€1.9M	Partial / short islanding	€4M	**~€10M**

Combining the terms for the four sectors currently under continuous monitoring gives:

Case	N_sectors	P_event	Consequence	Attribution	Expected benefit / year
Lower	4	1%	€3M	20%	**≈ €24,000**
Upper	4	3%	€10M	20%	**≈ €240,000**
Upper, favourable attribution	4	3%	€10M	50%	≈ €600,000

The third case is reported for completeness and not aggregated. It shows what the upper case would yield under the more favourable attribution described in Section 5.2.3; the reported range holds the 20% floor throughout.

The **expected annual benefit** therefore runs from about €24,000 at the conservative end to about €240,000 at the upper end, both applying the 20% attribution floor. Extending continuous monitoring from four to the ten planned critical sectors scales each figure by roughly two and a half, giving about €60,000–600,000 a year. The band is wide because its two weakest inputs compound: the annual probability spans 1–3% and the consequence €3–10 million, and the probability itself rests on expert judgement rather than on an event history for these corridors.

Limitations. Three limitations qualify the figures. The annual probability is the weakest input; the historical count of geotechnical events on these corridors, which GEB holds, would replace the assumption with operational data. The meshed structure of the grid means most line losses are rerouted instead of left unsupplied, so a full value-of-lost-load outage is the exception, not the norm, and the regulated unavailability penalty is the more realistic routine cost; that penalty value was not available. Finally, the calculation rests on benchmarks transferred from other settings and is presented as an illustrative expected value rather than an audited result.

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Júlia is an innovation consultant at the Brussels-based consultancy Evenflow, who work in collaboration with EARSC and the University of Oxford on the Sentinel Benefits Study (SeBS). Júlia graduated in Economics from Pompeu Fabra University (UPF) and moved to Brussels to pursue her career as a consultant in the space sector over 3 years ago. As part of the Erasmus exchange programme and before completing her bachelor's degree, she completed her Economics training at the Erasmus Universiteit Rotterdam (EUR). Júlia has been involved in SeBS-related work for several years, alongside numerous Horizon Europe projects and major contracts with ECMWF, Mercator Ocean International, and ESA, among others. This experience has equipped her with the research, analytical, and communication skills needed to carry out these studies.

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