Harnessing Asset-Level Data to Drive Climate and Nature Risk Adaptation

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Declaration of Interest Statement

The authors declare no conflict of interest.

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Abstract

As climate change and biodiversity loss accelerate, the need for precise, asset-level data to inform risk assessments and adaptation strategies is becoming increasingly critical. This paper explores the landscape of asset-level data sources, offering insights into their role in exposure and vulnerability analysis for climate and nature-related risks. Drawing on an extensive review of over 150 data providers spanning diverse sectors, including agriculture, infrastructure, and energy, we evaluate the methodologies, accessibility, and geographic coverage of these data sources. We emphasize the importance of high-resolution data -captured through remote sensing, geospatial analytics, and machine learning - for enabling granular assessments of physical, operational, and environmental characteristics of individual assets. These data are vital for policymakers, investors, and environmental organizations seeking to implement effective adaptation and resilience measures. However, the research also highlights significant gaps in data standardization, regional coverage, and accessibility, particularly in underrepresented areas. By addressing these gaps, we can enhance the accuracy of climate risk assessments and foster more robust global adaptation frameworks. This study contributes to the evolving field of asset-level risk analysis and underscores the critical need for improved data infrastructure to support sustainable development and climate resilience.

Introduction

As the impacts of climate change and biodiversity loss intensify, the need for effective risk assessment and adaptation planning becomes increasingly critical. Climate-related events alongside nature loss, present substantial risks to infrastructure, economies, and communities globally ().

While risk can be estimated using regional, sectoral, proxy, and scenario analysis, these methods have significant limitations for exposure-specific analysis (Arnell et al., 2021; van Dijk, 2020; Giannopoulos et al., 2013) (Silva, 2023; Ranger et al., 2023; Attoh et al., 2022). They do not consider asset properties and vulnerabilities, often missing critical factors such as extreme environmental conditions, structural integrity, and operational specifics (Bressan et al., 2023). Asset-level data, by providing detailed information about individual assets—including geographic location, physical characteristics, and environmental conditions—addresses these limitations. This specificity is essential for accurate risk assessments and the development of targeted adaptation measures, ensuring that investors, policymakers, and environmental organizations can make informed decisions to effectively mitigate risks and enhance resilience.

Exposure analysis at the asset level offers a granular approach that is crucial for identifying specific vulnerabilities and informing targeted adaptation measures.

Asset-level data includes detailed information about individual assets, including geographical location, physical characteristics and environmental conditions. This specificity is essential for accurate risk assessments and the development of targeted adaptation measures (UNEP FI, 2020). The importance of asset-level data can be illustrated through its application in understanding different types of exposure: physical, transition, and liability.

Data requirements at asset level vary significantly depending on the policy and project level.From coarse, aggregated data for high-level planning to granular, precise data for specific projects evaluations.

As decision-making processes advance, the necessity for integrating detailed, granular data becomes increasingly vital. This detailed data not only enhances the accuracy of risk assessments and justifies funding allocations but also supports the development of robust resilience standards. By incorporating granular data into broader planning, policymakers and financial institutions can better achieve comprehensive climate and nature-related goals, ensuring more effective climate adaptation and resilience strategies.

While risk can be estimated using regional, sectoral, proxy, and scenario analysis (Arnell et al., 2021; van Dijk, 2020) (Giannopoulos et al., 2013), these methods have significant limitations for the asset-specific

(Silva, 2023; Ranger et al., 2023)(Attoh et al., 2022). They do not consider unique characteristics, vulnerabilities and often miss critical factors such as extreme environmental conditions, structural integrity, and operational specifics (Bressan et al., 2023). For critical insightful, analysis re

Asset-level data provides for investors, policymakers, and environmental organizations.

By examining the distinct attributes of physical assets, investors can identify high-vulnerability areas and direct investments toward regions needing adaptive interventions. This data-driven approach ensures efficient resource allocation and maximises the impact of adaptation efforts

(CFRF, 2024). Moreover, asset-level data informs strategic planning and decision-making, such as investing in infrastructure upgrades to enhance resilience to severe weather, or adopting technologies to reduce water consumption in drought-prone areas (Rahman, Jiang & Irvine, 2018).

Asset-level data also drives innovation and technology adoption. For instance, energy efficiency data can stimulate investments in green building technologies, while water usage information can lead to more effective irrigation systems (Nost, 2019). This data fosters collaboration among stakeholders by providing a common understanding of climate risks and opportunities. Public-private partnerships can pool financial resources for large-scale adaptation projects, like coastal defences or urban green spaces (Sohail et al., 2022).

Various sectors benefit from integrating asset-level data. The health and education sectors use it for facilities and infrastructure planning (Mochizuki & Naqvi, 2019). Financial institutions and investors rely on granular data to assess the financial impacts of climate risks, perform climate stress tests, and align strategies with sustainability goals (Tankov & Tantet, 2019; UNEP & UNEP FI, 2024). Policymakers use this data for infrastructure resilience and sustainable development (UNDRR, 2023). Urban planners need detailed spatial and socio-economic data for disaster risk reduction and urban development (Herfort et al., 2023). Researchers use asset-level data for studies on climate and nature loss adaptation planning and risk mitigation (Van Raalte, D. Ranger, 2023; Espinoza et al., 2023).

However, gaps, inconsistencies, and accessibility barriers in the current landscape of asset-level data hinder effective decision-making. Incomplete data coverage, especially in underrepresented regions, and outdated data pose significant challenges. For example, accurate risk assessments require detailed datasets, as seen in managing antimicrobial resistance (AMR), vector-borne diseases, biological hazards, invasive species, forest ecosystems, and coastal management and other types of climate and nature-related hazards (Boston Consulting Group, 2022; Hughes, Roe & Hocknell, 2021; Smith et al., 2015; Greenwood & Warren, 2022; Keenan, 2015; Goldsmith, Granek & Lubitow, 2015; Lawrence et al., 2021) (Eberenz et al., 2020; Dikanski, Imam & Hagen-Zanker, 2018; Halsnæs & Kaspersen, 2018). Furthermore, asset-level data require development of standardisation frameworks to ensure technical, retrieval, and scientific consistency (Popp et al., 2020)(Loris et al., 2023). The lack of timeliness and currency of data and accessibility issues hinder data usability and require additional technical, financial, and legal solutions (Lu, Tighe & Xie, 2018; Kolozsi, Ladányi & Straubinger, 2022).

A few lines on boots in remote sensing but a shortfall in understanding how to use it, cost, and early stages of adoption.

In this review, we analyse the current landscape of asset-level data for climate and nature related risk assessment and adaptation planning based on data suppliers market research, open access datasets, stakeholder interviews, and case studies from different environmental domains. Our study examined over 150 data sources, encompassing both commercial and open-source databases. The analysis covers a wide range of sectors, including agriculture, natural resources, production, extraction, energy, industry, infrastructure, urban development, finance, technology, health care, retail, transport, climate, environment, government and other issues such as disaster management and community services.

We focus on both the tangible and intangible assets and examine five critical dimensions of asset-level data: location data, physical characteristics, operational specifics, environmental exposure, and financial information. In our evaluation of data sources, we considered available assets, methodology, spatial coverage, data attributes, accessibility, timeliness, pricing, and usability for risk analysis and adaptation planning.

This study contributes to the existing literature in two primary ways. First, it provides a detailed mapping of the emerging asset-level data landscape, identifying critical gaps and challenges that hinder effective environmental risk assessment and adaptation planning. Secondly, it provides insights into the need for improved data resolution, standardisation, and accessibility to support robust risk assessments, not only for climate and nature-related risk assessments, but also for adaptation planning.

Methodology

A systematic approach was adopted to identify relevant data sources. Main steps included:

- A review of existing literature, including academic papers, industry reports and white papers;
- Discussions with industry experts and practitioners;
- …

Our primary focus was on data providers that offer asset-level data, explicitly delineated their methods for data collection and processing, consider global domain, have clear subscription models or those that offer publicly accessible data.

Table 1 Asset Data Dimensions and Methodologies

Data Type	Description	Methodology
Spatial Location	High-resolution geographical data, including coordinates, elevation, and mapping information.	Remote sensing, satellite imagery, geospatial data
Environmental Hazard	Information on environmental conditions and potential climate/nature loss hazards.	Remote sensing, satellite imagery, field surveys
Physical and Infrastructure Characteristics	Details about the physical attributes of assets.	Field surveys, direct data collection, geospatial mapping
Operational and Performance	Data on asset utilization, maintenance records, and operational performance metrics.	Machine learning, AI, direct data collection
Financial and Actuarial Information	Financial metrics, insurance coverage details, and actuarial data.	Statistical and econometric models, financial data analysis

Information on each data provider, including their methodologies, accessibility, coverage, and use cases, was extracted. This involved accessing provider websites, published reports, and databases. Extracted data was compiled into a structured dataset. Key attributes included the sector, data source, global coverage, methodology, data format, accessibility, and specific use cases.

Data were cross verified with multiple sources to ensure accuracy and reliability. The compiled dataset was reviewed by industry experts to validate the selection criteria and the categorisation of data providers. The analysis was carried out in accordance with ethical standards and, where applicable, ensured the confidentiality of proprietary information.

Asset-Level Data.

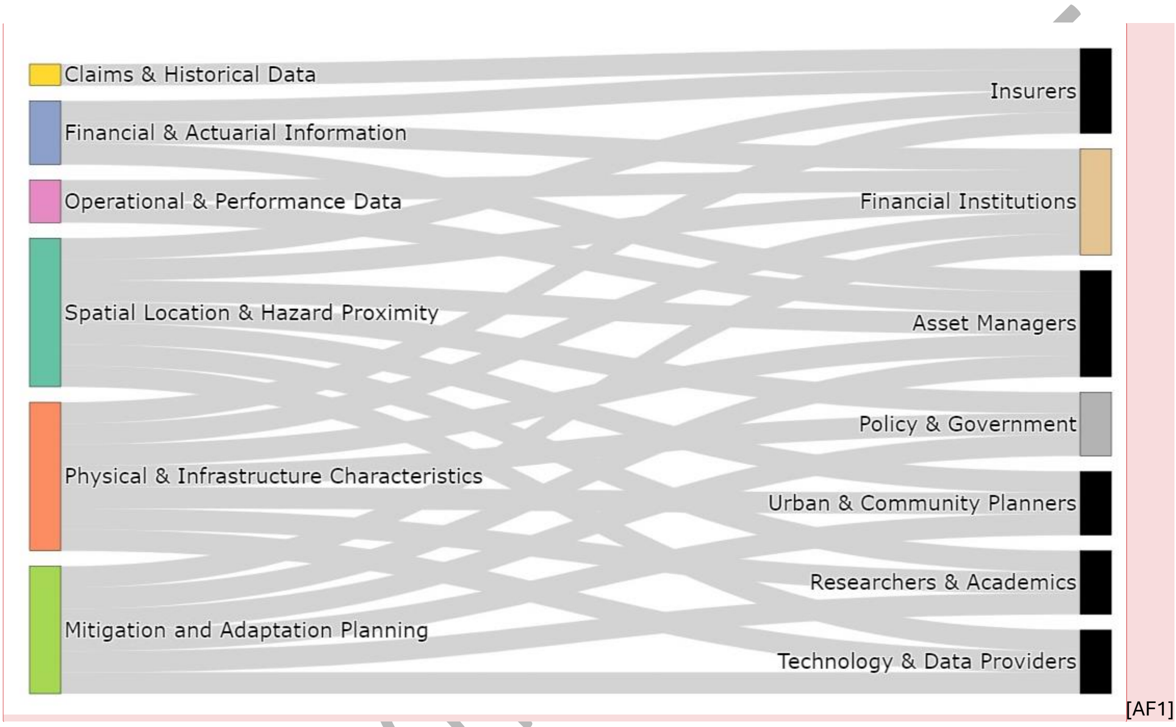
Figure x shows the presence of each data type required by the stakeholders.

Spatial Location & Hazard Proximity

Data Types

Suppliers

Figure 1. Heatmap of Data Needs for Risk and Resilience Assessment



[AF1]

Figure x illustrates the presence of different data types required by various groups of stakeholders based on () and expert consultations to identify the primary data needs.

A strong demand for Location, Spatial Data and Environmental Exposure across all stakeholder groups, reflecting the need for precise geographical and environmental information.

Financial Institutions, Asset Managers, and Insurers also require extensive data on Physical & Infrastructure Characteristics and Financial & Actuarial Information to evaluate the risks and financial implications of climate change. Policymakers and Urban Planners prioritise Regulatory & Compliance Data and Scenario & Mitigation Planning to develop effective policies and strategies. Researchers and Academics emphasise Community & Socio-Economic Data for comprehensive climate impact studies.

Spatial Location Data

Accurate location data facilitates mapping of a broad range of products supply chains, identification of critical intervention points, and improvement of logistical efficiency.

Leveraged to optimize urban food systems, minimizing waste and enhancing sustainability and resilience in cities. Food production sites, distribution centres, retail outlets, and areas experiencing food shortages. Arup. (2022). Urban Eats: How cities can leverage opportunities to build resilient food systems through circular pathways. Resilient Cities Network.

Leveraged to optimize critical mineral supply chains, enhancing resilience (Cambridge, 2024)

Optimal resource allocation and equitable access to infrastructure services rely heavily on location-specific data, such as power plants, transportation hubs, water treatment facilities, and areas prone to environmental hazards. Accurate location data helps in mapping critical infrastructure networks, identifying vulnerable regions, and enhancing logistical efficiency.

Coalition for Disaster Resilient Infrastructure (CDRI). (2023). Global Infrastructure Resilience: Capturing the Resilience Dividend - A Biennial Report from the Coalition for Disaster Resilient Infrastructure. CDRI Secretariat, New Delhi. ISBN: 978-81-965011-0-5. Retrieved from https://www.cdri.world/biennial-report

All of this holds significance within the realm of mining and industrial operations. Furthermore, precise location data is necessary for effective carbon and emissions monitoring in order to accurately trace emission sources and their effects on achieving net zero.

Environmental Hazard

Although environmental exposure data are intertwined with spatial location, both categories serve distinct purposes. Spatial location data helps to map and understand the physical placement of assets, whereas hazard data highlights potential risks. Thus, main emphasis of spatial location data is on the exact geographical coordinates and arrangement of assets. Conversely, the data on environmental exposure emphasizes the potential risks that environmental elements pose to these assets, requiring additional sources such as past climate records, environmental pollution, resource extraction, and other type environmental studies. The methodological differences also demonstrate this divergence, as spatial data largely relies on on-the-ground surveys and precise mapping technologies, while environmental hazard data incorporates datasets for modelling complex environmental phenomena (e.g., weather patterns, environmental pollution, pathogen spread) to create models and anticipate environmental hazards.

Physical and Infrastructure Characteristics

Physical characteristics (e.g. construction, size, materials, age, and condition), fundamentally influence an asset's resilience or susceptibility to damage from environmental changes and disasters. Research into the resilience of seaports to climate change reveals how physical characteristics of port assets, including their design and location, determine their vulnerability and adaptation strategies to sea-level rise (Chhetri et al., 2015).

Understanding physical and infrastructural characteristics is essential for several scenarios, particularly environmental risk assessments. For[AF2] instance, information about how infrastructure withstands environmental stressors and evaluates structural resilience to natural disasters is critical for developing sustainable infrastructure (Arup, 2024). Similarly, mining and industrial activities require detailed physical data to understand their environmental and structural impacts (net zero paper, 2023).

In the context of habitat and biodiversity monitoring, physical data helps track changes and impacts on biodiversity. Studies have shown how specific physical characteristics of habitats influence species distribution and ecosystem health (ECI). Additionally, for ecosystem service valuation, assessing the benefits provided by ecosystems requires understanding their physical attributes.

Monitoring deforestation and land degradation also relies heavily on physical characteristics to identify and address affected areas. For instance, Van Wilgen et al. (2018) highlight the importance of physical data in assessing land degradation and planning restoration efforts.

Understanding the physical characteristics of assets is crucial for implementing resilience strategies in urban food systems. In Pune, India, the SWaCH model integrates waste pickers into the formal waste management system, necessitating detailed knowledge of waste segregation and collection processes. The physical attributes of waste processing facilities, such as composting plants, are also vital for determining their capacity to handle organic waste and convert it into valuable products like biogas. This information supports the design and operational efficiency of waste management systems, contributing to overall urban resilience.

Operational & Performance Data

Operational and performance, focusing on asset use, maintenance history, and performance metrics, is important to monitor and optimise operational efficiency, assess operational risks and plan for maintenance and upgrades.

In Urban and Community Planning, this data ensures sustainable development and efficient resource use (). Infrastructure Risk Assessments use operational data to monitor the performance of infrastructure systems (). Monitoring operational impacts is crucial for Mining and Industrial Activities (). In Habitat and Biodiversity Monitoring, operational data tracks the effectiveness of conservation efforts (). Ecosystem Service Valuation and monitoring Deforestation and Land Degradation also depend on operational data (). General Operational Performance Monitoring is critical for maintaining company-wide efficiency. However, operational data is less relevant for environmental exposure assessment, climate hazards risk Assessment, and similar scenarios.

Example: The development of a theoretical framework for the integrated vulnerability of businesses to sea level rise demonstrates how operational specifics, including business characteristics and infrastructure factors, play a role in assessing business vulnerability to environmental hazards (Song et al., 2016).

Financial & Actuarial Information

Economic impact assessments rely heavily on financial and actuarial information. For Infrastructure Risk Assessments, this data helps evaluate the economic ramifications of potential risks (Arup, 2024). Ecosystem Service Valuation depends on financial data to assess the monetary value of ecosystem benefits (NbS, 2024). Conservation Planning uses financial information to support the economic rationale for conservation efforts (ECI, 2024).

General Financial Risk Assessments are conducted using macroeconomic data, which does not require location-specific information (Green Scorpion, 2023). Financial audits are also crucial for ensuring compliance in Regulatory Compliance Checks (CGFI, 2023).

Data Collection Methods

The methods used for collecting assets characteristics and properties include remote sensing, satellite imagery, geospatial data and mapping, field surveys and direct data collection, machine learning and AI, crowdsourced and user-contributed data, statistical and econometric models, and the integration of multiple data sources. Leveraging these diverse techniques, data providers deliver comprehensive and accurate datasets essential for informed decision-making across various sectors.

Remote Sensing and Satellite Imagery

The remote sensing industry has evolved significantly, shifting from government-dominated, coarse-resolution data to high-resolution, commercially available images provided by a growing number of private companies (Weber et al., 2017). Advances in sensor technology, computing power, and data storage have led to significant improvements in the resolution and availability of remote sensor data. The launch of high-resolution IKONOS satellites in 1999 marked a shift to more detailed and commercially viable images. The entry of commercial entities, including DigitalGlobe (now Maxar Technologies), GeoEye, and Airbus Defence and Space, expanded the market (Maxar Technologies, 2022; Airbus, 2022).

The free availability of Landsat data since 2008 has facilitated equal access to remote sensing data, encouraging innovation and wider adoption (NASA, 2022).

From 2010 to 2020, the emergence of new enterprises, such as Planet Labs, transformed the field with constellations of small, affordable satellites capable of delivering frequent and nearly instantaneous data (Planet Labs, 2022). This period saw a rise in data suppliers and increased competition, leading to more affordable and accessible data. The integration of remote sensing data with GIS, AI, and machine learning tools has significantly enhanced data analysis capabilities. Companies, including Google and Microsoft, have played pivotal roles in this integration through platforms such as Google Earth Engine and Microsoft Azure Machine Learning (Google Earth Engine, 2022; Microsoft Azure, 2022).

The commercialization of remote sensing data is growing rapidly, with an increasing number of private companies entering the market. Leading firms such as Maxar Technologies, Airbus Defence and Space, and Planet Labs offer high-resolution imagery and specialized services. This trend is primarily driven by the demand for precise, timely data in sectors including agriculture, urban development, and environmental monitoring (Maxar Technologies, 2022; Airbus, 2022). Technological advancements have improved the cost-efficiency and accessibility of remote sensing data. Companies such as Spire Global and BlackSky deploy cost-effective CubeSats, which provide frequent, high-resolution imagery. This miniaturization of satellite technology reduces barriers to entry and increases data availability, making remote sensing more accessible to small businesses and researchers (Spire Global, 2022; BlackSky, 2022).

Current market leaders such as Planet Labs and Maxar Technologies are enhancing their satellite capabilities, while emerging players such as Satellogic and ICEYE offer high-resolution, timely data. This trend enables precise, rapid decision-making in critical situations, improving outcomes in emergency management and resource optimization in agriculture and urban settings (Planet Labs, 2022; ICEYE, 2022).

The integration of remote sensing data with AI, machine learning, and big data analytics is transforming the field. Companies such as Google, Microsoft, and IBM are at the forefront of this integration, providing deeper insights and robust solutions. Startups such as Descartes Labs and Orbital Insight are also driving advancements by developing innovative applications in environmental monitoring, resource management, and smart city projects (Google Earth Engine, 2022; Microsoft Azure, 2022; IBM Watson, 2022; Descartes Labs, 2022; Orbital Insight, 2022). These technologies enhance the ability to analyze vast amounts of data quickly and accurately, leading to more informed decision-making and strategic planning.

Recognizing that remote sensing is essential for addressing sustainability challenges such as deforestation, air and water quality, and climate change, companies such as SkyTruth and Global Forest Watch provide monitoring data and advocate for policy reforms (SkyTruth, 2022; Global Forest Watch, 2022). Organizations such as the United Nations Environment Programme (UNEP) and the European Space Agency's Copernicus program use remote sensing for sustainability initiatives and policy decisions (UNEP, 2022; Copernicus, 2022).

To address the global demand for data, there is a positive trend towards open data and collaboration. Programs including the European Space Agency's Copernicus and NASA's Earth Observing System Data and Information System (EOSDIS) provide free access to vast remote sensing datasets, fostering innovation and new applications. The Radiant Earth Foundation and Planet Labs support collaboration by offering extensive open data, enabling researchers and developers to create novel solutions to complex challenges (Copernicus, 2022; NASA EOSDIS, 2022; Radiant Earth Foundation, 2022).

Continuous improvements in satellite technology by government agencies ensure the availability of high-quality data. Innovations such as synthetic aperture radar (SAR) by ESA and high-resolution optical sensors by NASA contribute to the richness of the data (ESA, 2022; NASA, 2022). Government agencies provide extensive temporal and spatial coverage, often implementing open access policies to promote equitable distribution and utilization of remote sensing data, foster innovation, and facilitate diverse applications (NASA, 2022; ESA, 2022).

Private companies bring innovation and agility, providing high-resolution, near-real-time data for specific industry needs such as agriculture, urban planning, and disaster response. The synergy between government-provided open access data and specialized, high-resolution data from private companies creates a robust remote sensing ecosystem. This ecosystem supports a wide range of applications, from global climate models to local precision farming, enabling informed decision-making.

The combination of remote sensing data with other sources (e.g., IoT sensors, ground-based observations) and advanced analytics (e.g., AI-driven analysis) has become more prevalent. This enhances the ability to derive actionable insights and supports more comprehensive decision-making. Companies such as IBM Watson and H2O.ai are at the forefront of integrating advanced analytics with remote sensing data (IBM Watson, 2022; H2O.ai, 2022).

The emergence of cloud-based platforms such as Google Earth Engine has made it easier for users to access, process, and analyze large volumes of remote sensing data. This has facilitated wider adoption across various sectors, enabling more users to leverage remote sensing data for their specific needs (Google Earth Engine, 2022).

Geospatial Data

Both remote sensing imagery and geospatial data maps have seen substantial evolution since the 1960s, supported by a mix of governmental and private entities. Despite core similarities between methods, there is notable distinctions exist between them in terms of data types, access methods, temporal progressions, and global development patterns. Remote sensing data primarily includes satellite and aerial imagery, LiDAR, and radar data. In contrast, geospatial data encompasses a wide array of sources, including topographic maps, GPS data, and spatial databases obtained through ground surveys, IoT sensors, and crowdsourcing.

Geospatial data and mapping providers include not only satellite operators but also companies providing Geographic Information System (GIS) tools, such as Esri and HERE Technologies, and platforms for crowdsourced data like OpenStreetMap (Haklay & Weber, 2008). Pre-processed platforms such as ArcGIS, QGIS, Google Earth Engine, and other cloud-based GIS services offer user-friendly interfaces and analytical tools that streamline data manipulation and visualization (Google Earth Engine, 2022).

Technological advancements in remote sensing focus on enhancing the resolution, frequency, and real-time capabilities of satellite imagery, while geospatial data trends prioritize integrating diverse data sources, such as IoT sensors and crowdsourced information, and improving user-friendly GIS tools. Geospatial data emphasize integrating both local and global data, often customizing solutions to meet specific regional requirements.

Government agencies and private companies play pivotal roles in geospatial data advancements. For instance, the ArcGIS platform developed by Esri has significantly transformed the industry by providing powerful GIS tools that enable intricate spatial analysis in multiple sectors, such as agriculture, transportation, and public health (Esri, 2022). The UK's Ordnance Survey offers accurate geospatial data and mapping services to assist with infrastructure development and environmental assessments (Ordnance Survey, 2021). SuperMap provides advanced GIS solutions, while Google Maps Platform and Google Earth Engine offer comprehensive geospatial data and analytical tools critical for urban planning and environmental monitoring (SuperMap, 2021).

The precision and accuracy of geospatial data have greatly improved due to the combination of high-resolution satellite imagery, LiDAR, and drone-based data collection. Esri, HERE Technologies, and Google are spearheading advancements in GIS technologies. AI-based analytics have revolutionized the analysis of geospatial data, revealing previously inaccessible patterns and insights. For example, Orbital Insight and Descartes Labs use artificial intelligence to enhance geospatial analytics for environmental monitoring, urban development, and resource management purposes.

Fugro and Trimble exemplify multi-source approaches, offering advanced solutions for industries (Trimble, 2022). TomTom's real-time traffic data and Esri's real-time GIS capabilities provide up-to-date information essential for these applications. Precisely use a combination of proprietary algorithms and data sources to deliver precise geolocation services. These data are increasingly demanded for applications in disaster response, traffic management, and urban planning.

Geospatial data accessibility has been enhanced through cloud computing and data visualization tools. Google Earth Engine and Microsoft Azure Maps enable users to process and analyse large amounts of spatial data without extensive local infrastructure, while also providing strong visualization capabilities. In developed regions, the adoption of advanced geospatial technologies is driven by robust infrastructure and financial resources. Conversely, developing regions leverage open data and cost-effective technologies to enhance their capabilities, supported by organizations such as the UN and the World Bank.

OpenStreetMap (OSM) plays an important role in democratizing the collection and dissemination of geospatial data. By enabling users to contribute and update geographical information, OSM produces highly detailed and current maps. Crowdsourcing initiatives have democratized data collection, promoted transparency, and enhanced the quality and accessibility of geospatial information, thereby supporting informed decision-making and fostering innovation across various sectors.

Crowdsourced and User-Contributed Data

Data coverage and granularity can be enhanced by leveraging the collective input of individuals and organizations, crowdsourced and user-contributed data methods. The origins of crowdsourcing in geospatial contexts can be traced back to the early 2000s, with the emergence of OpenStreetMap (OSM) (Haklay & Weber, 2008).

The phenomenon grew. The Open Supply Hub, established with the purpose of enhancing transparency in global supply chains and infrastructure, relies on collaborative input to offer comprehensive mappings of supply networks, thus advocating for ethical sourcing and environmental sustainability (Open Supply Hub, 2021).

A notable trend in this area is the integration of crowdsourced data with advanced technologies. For example, Mapillary, established in 2013 and subsequently acquired by Facebook, gathers street-level imagery through user submissions. The data is processed using artificial intelligence and machine learning algorithms to generate comprehensive maps that aid in urban planning and infrastructure development (Mapillary, 2022; Zhao & Ramage, 2022).

Another noteworthy advancement is the involvement of non-governmental organizations in utilizing crowdsourced data for environmental monitoring. Global Forest Watch, established in 2014, employs crowdsourced inputs to monitor deforestation and forest degradation. By integrating real-time updates from volunteers, the platform offers practical information that supports conservation efforts and informs policymaking (Hansen et al., 2013).

Furthermore, the Environmental Justice Atlas (EJAtlas) serves as a prime example of the efficacy of crowdsourced data in documenting environmental conflicts on a global scale. Established in 2012, the EJAtlas gathers and organizes case studies submitted by activists, scholars, and community members. This platform offers comprehensive information on environmental justice issues, providing valuable insights into the socio-environmental consequences of different projects and policies (Martínez-Alier et al., 2016).

The increasing accessibility of technology has further fuelled the growth of crowdsourced data. The proliferation of smartphones and GPS-enabled devices has made it easier for individuals to contribute data, leading to richer and more granular datasets (Goodchild, 2007).

Field Surveys and Direct Data Collection

Initially characterized by manual data collection with a limited scope, field surveys have evolved significantly over time, incorporating digital transformation to enhance accuracy, efficiency, and the breadth of data acquisition. Currently, these methods can be broadly classified as direct surveys, conventional corporate reporting, industry-led initiatives, and online searches (Weber et al., 2017).

Obtaining detailed asset-level data involves direct contact with companies through surveys and communication. This includes one-on-one interactions, written surveys, direct data feeds, and participation in investor relations activities such as shareholder meetings. The Bureau of Transportation Statistics (BTS) and the United States Geological Survey (USGS) exemplify this approach, conducting thorough surveys and utilizing direct communication to gather data on transportation and geological resources, respectively (BTS, 2022; USGS, 2022). Similarly, FAOSTAT, overseen by the Food and Agriculture Organization (FAO), gathers worldwide agricultural information via direct surveys with relevant parties (FAOSTAT, 2021).

Traditional corporate reporting, including ESG reporting, involves formal mechanisms where companies disclose financial and non-financial data through structured reports. Entities such as CDP (Carbon Disclosure Project), Bloomberg Terminal, MSCI, GRESB, Green RWA, Ortec Finance and Sustainalytics rely heavily on these disclosures to compile comprehensive databases assessing corporate environmental performance, social impact, and governance practices (CDP, 2022; Bloomberg, 2022; MSCI, 2022; Sustainalytics, 2022). This method has seen significant growth over the past two decades, driven by increasing regulatory demands and stakeholder expectations for transparency.

Industry-led initiatives play a crucial role in gathering asset-level data not publicly disclosed. Examples include WorldSteel's collection of CO2 emissions data and the Cement Sustainability Initiative's database, known as Getting the Numbers Right (GNR). These initiatives gather industry-specific environmental performance data, providing critical information for comparing and establishing industry-wide standards (WorldSteel, 2022; GCCA, 2022).

Many commercial data providers use customized web crawlers and automated searches to collect announcements about new assets from primary and industry/trade press sources and company websites. This method is particularly effective for capturing real-time updates and new asset information. Companies such as IHS Markit PI and GlobalData employ these techniques to collect and regularly update their databases (IHS Markit, 2022; GlobalData, 2022).

There exists a notable disparity in the implementation and refinement of these techniques across different geographical areas. North America and Europe are leading the way, driven by stringent regulatory frameworks and advanced technological infrastructure. Asia is rapidly advancing with substantial investments in technology-based data gathering. In contrast, regions such as Africa and parts of South America are in the initial phases, focusing on developing essential infrastructure and regulatory frameworks to facilitate comprehensive data gathering (FAOSTAT, 2021; USGS, 2022).

Machine Learning (ML) and Artificial Intelligence (AI)

The incorporation of ML and AI is greatly transforming the procedure of gathering asset-specific information by enabling the automated examination of extensive datasets; these advancements are used to detect patterns, forecast trends, and enhance the precision of data analysis.

The rapid evolution of these technologies can be attributed to the initial advancements in computational power and data storage during the late 1990s and early 2000s. The decade of 2010 witnessed a significant shift with the implementation of AI-driven platforms and the widespread use of IoT devices, resulting in the ability to collect and analyse real-time data on a scale never seen before.

ML and AI are embedded in various data collection methodologies previously discussed, particularly in remote sensing and geospatial data analysis. Various entities, including government agencies such as ESA and NASA, private companies like Google and Esri, and platforms like Climate TRACE and Orbital Insight, employ artificial intelligence to process and analyse satellite imagery and other geospatial data for the purposes of climate action and environmental monitoring. Non-governmental organizations such as Global Forest Watch and SkyTruth utilize artificial intelligence to improve and expedite real-time environmental monitoring and conservation initiatives. The collaboration between governmental entities, private sector leaders, and non-governmental organizations is essential in maximizing the potential of these technologies to address global environmental challenges.

Physical Characteristics and Operational Data

In the past, information regarding physical attributes was collected through manual examinations and surveys, which required experts to conduct on-site visits to assess assets and document measurements. The design and specifications were documented in blueprints and technical drawings, which proved to be difficult to maintain for larger assets (Autodesk, 2021; Bentley Systems, 2021).

Technological advancements have transformed physical data collection. 3D laser scanning and LiDAR technology create highly accurate 3D models, with companies such as FARO Technologies and Leica Geosystems providing these solutions (FARO Technologies, 2021; Leica Geosystems, 2021). Drones equipped with high-resolution cameras are utilized to capture detailed imagery for the purpose of creating 3D models, with DJI, PrecisionHawk, and senseFly being prominent leaders in this field (DJI, 2021; PrecisionHawk, 2021).

Geographic Information System (GIS) technology combines and evaluates spatial data, while Building Information Modeling (BIM) software, such as Autodesk Revit and Bentley Systems' AECOsim, generates intricate 3D models incorporating both design and operational information (Autodesk, 2021; Bentley Systems, 2021).

In terms of operational performance, IoT technology and smart sensors are currently utilized to monitor and transmit real-time data on various parameters, including temperature and energy consumption. This is made possible through the provision of comprehensive IoT solutions by companies such as Siemens, GE Digital, and Schneider Electric (Siemens, 2021; GE Digital, 2021; Schneider Electric, 2021). Augmented Reality (AR) and Virtual Reality (VR) technologies serve to enhance the visualization and analysis of data. PTC (Vuforia), Microsoft (HoloLens), and Dassault Systèmes lead in AR and VR solutions (PTC, 2021; Microsoft, 2021; Dassault Systèmes, 2021). Robotic Process Automation (RPA) streamlines repetitive tasks, resulting in enhanced precision. UiPath, Blue Prism, and Automation Anywhere provide RPA solutions according to their respective websites (UiPath, 2021; Blue Prism, 2021; Automation Anywhere, 2021).

Artificial intelligence and machine learning enhance the analysis of data by predicting potential failures and optimizing maintenance, resulting in improved asset performance and reduced costs. IBM, Google AI, and Uptake are leading the industry (IBM, 2021; Google AI, 2021; Uptake, 2021). Cloud-based platforms for data storage and analysis offer increased scalability and remote accessibility, thereby enhancing data management capabilities (IBM, 2021; SAP, 2021; Oracle, 2021).

Financial Data

Historically, financial data was collected through the use of financial statements and actuarial valuations. Although these methods were precise, they were also labour-intensive and required a substantial amount of manual labour. Enterprise Resource Planning (ERP) systems effectively integrate financial data with other business processes, enabling real-time monitoring and reporting. The companies SAP, Oracle, and Microsoft Dynamics provide ERP solutions (SAP, 2021; Oracle, 2021; Microsoft Dynamics, 2021). Detailed analysis is enabled by advanced financial analytics and BI tools. According to the latest data from Tableau, Qlik, and Microsoft Power BI (Tableau, 2021; Qlik, 2021; Microsoft Power BI, 2021), these three companies are currently leading in the field of business intelligence tools.

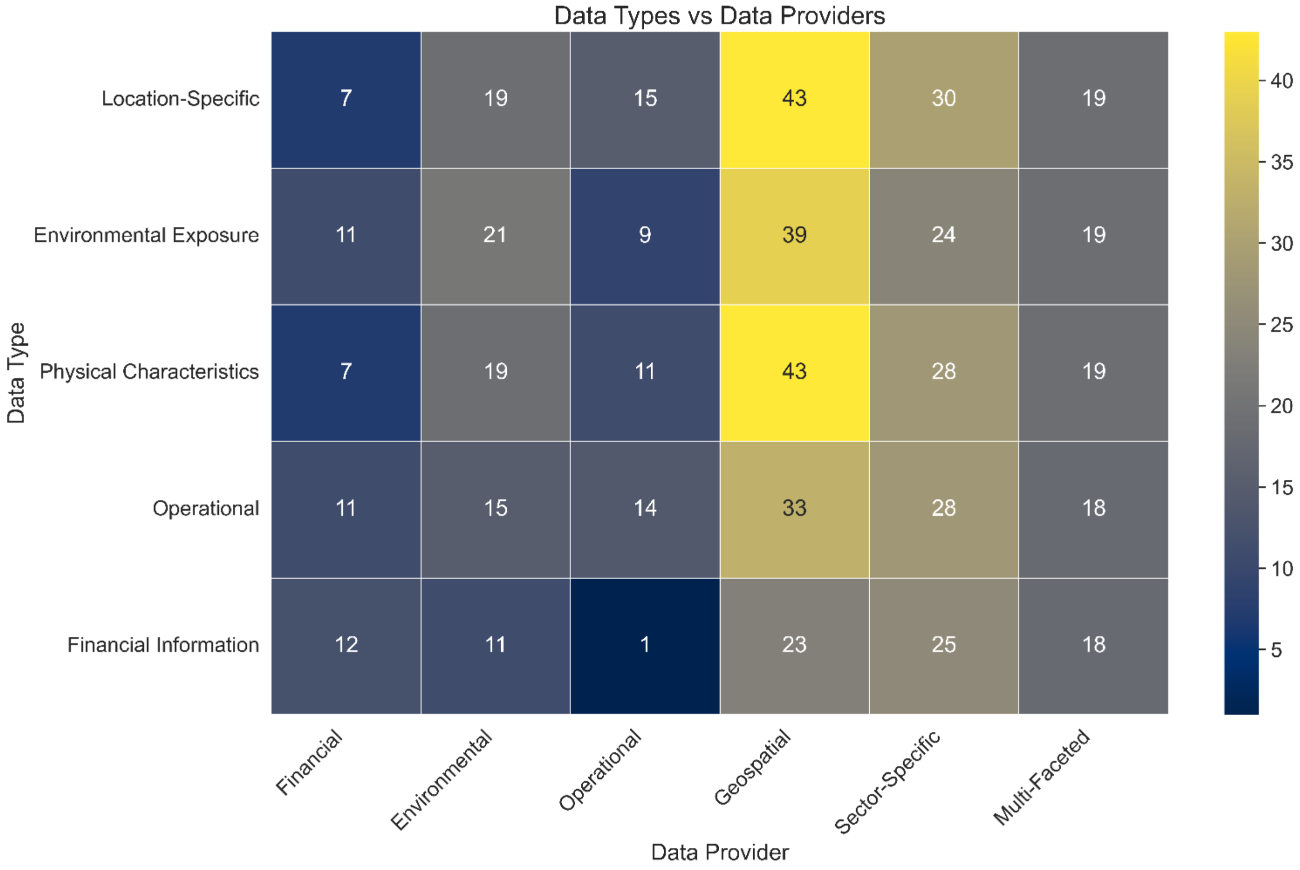
The utilization of blockchain technology by IBM and ConsenSys has been demonstrated to enhance data integrity and transparency, as evidenced by their respective advancements (IBM, 2021; ConsenSys, 2021). The automation of financial data collection and processing is facilitated by RPA, with UiPath, Blue Prism, and Automation Anywhere offering their respective solutions (UiPath, 2021; Blue Prism, 2021; Automation Anywhere, 2021).

Artificial intelligence and machine learning have shown to enhance financial data analysis by identifying trends and optimizing strategies. Prominent companies such as BlackRock, IBM, and Google AI are leading the way in this field (BlackRock, 2021; IBM, 2021; Google AI, 2021). As adaptation, sustainability and impact investing becomes more critical, there is a growing need for real-time financial monitoring and predictive analytics tools. These tools have been created to evaluate the sustainability and impact of investments (BlackRock, 2021; Morningstar, 2021; ImpactAssets, 2021).

Integration of Multiple Data Sources

The integrative approach is demonstrated through cooperative endeavours such as the GeoAsset Project and Climate TRACE, which aggregate information from satellites, sensors, field surveys, and other methods, offering a diverse viewpoint on data at the asset level. The GeoAsset Project, spearheaded by the Centre for Global Finance and Innovation (CGFI), integrates geolocated asset data for environmental and financial analysis, aiding in sustainable investment and policy decisions (CGFI, 2022). Similarly, Climate TRACE uses AI to fuse data from a variety of sources, providing real-time monitoring of global greenhouse gas emissions and supporting climate action and accountability (Climate TRACE, 2021). By leveraging diverse data streams, these initiatives can provide a more nuanced understanding of asset dynamics, cross-validating different sources.

Table: Methodologies for Gathering Asset-Level Financial and Actuarial Information



Data Types vs Data Providers

Data Type	Financial	Environmental	Operational	Geospatial	Sector-Specific	Multi-Faceted
Location-Specific	7	19	15	43	30	19
Environmental Exposure	11	21	9	39	24	19
Physical Characteristics	7	19	11	43	28	19
Operational	11	15	14	33	28	18
Financial Information	12	11	1	23	25	18

Data Providers

Government Organizations

Government organizations leverage extensive resources and technological proficiency to gather datasets that support public policy, environmental monitoring, and scientific research.

NASA, the primary space agency in the United States, provides essential satellite data through missions such as Landsat and MODIS, which are extensively used for monitoring urban development and identifying potential environmental hazards (Roy et al., 2014; Wulder et al., 2019). The US Geological Survey (USGS) offers comprehensive geological and hydrological data, ensuring dependable information for resource management and environmental protection (USGS, 2021).

The European Space Agency (ESA) manages the Copernicus program in Europe, providing high-resolution satellite images through the Sentinel series, which play a crucial role in global environmental monitoring and disaster response (Aschbacher & Milagro-Pérez, 2012). The Ordnance Survey (OS) in the UK supplies maps and data to aid infrastructure and environmental monitoring (Ordnance Survey, 2021). The Indian Space Research Organization (ISRO) and the China National Space Administration (CNSA) offer high-resolution geospatial and comprehensive satellite data, respectively (ISRO, 2022; CNSA, 2022). Additionally, the Surveying and Mapping Institute of China provides cartographic data for infrastructure projects and environmental assessments. The Japan Aerospace Exploration Agency (JAXA) offers advanced remote sensing data through its ALOS missions, which are critical for disaster preparedness and urban planning (JAXA, 2021).

Private Companies

Private enterprises are at the forefront of advancing data collection, analysis, and distribution at the asset level, driven by commercial goals to provide state-of-the-art solutions. DigitalGlobe, a subsidiary of Maxar Technologies, is renowned for its high-resolution satellite imagery used in environmental monitoring and national security (DigitalGlobe, 2020). Esri's ArcGIS platform has revolutionized spatial analysis with comprehensive GIS tools that aid decision-making across various industries, including agriculture, transportation, and public health (Esri, 2022). Planet Labs employs a network of small satellites to provide regular, detailed imagery of the Earth's surface, enabling real-time environmental monitoring and land use management (Planet Labs, 2022).

Google offers extensive geospatial data and analytical tools through its Google Maps Platform and Google Earth Engine (Google Earth Engine, 2022). SuperMap provides advanced GIS solutions for spatial data management (SuperMap, 2021). Bluesky International offers comprehensive aerial photography and LiDAR data essential for urban planning and infrastructure development (Bluesky International, 2021). Topcon Corporation specializes in precision measurement and positioning solutions for construction and surveying projects (Topcon Corporation, 2022), while Terra Drone Corporation offers drone-based solutions for aerial surveys and inspections (Terra Drone Corporation, 2022).

Non-Governmental Organizations (NGOs)

NGOs play a crucial role in addressing issues such as sustainability, human rights, and resource management through independent data collection. The Carbon Disclosure Project (CDP) gathers detailed information on the environmental impacts of corporations, advocating for transparency and sustainable practices (CDP, 2021). Global Forest Watch uses satellite technology for real-time deforestation monitoring, supporting conservation efforts and enabling policymakers and the public to respond effectively to environmental threats (Global Forest Watch, 2022). The Open Supply Hub collects data to enhance supply chain transparency, promote ethical sourcing, and reduce environmental impacts (Open Supply Hub, 2021).

Academic, Research Institutions and Collaborations

Academic and research institutions advance rigorous scientific studies and high-quality, peer-reviewed data. Collaborative initiatives integrate the strengths of governments, private companies, NGOs, and academic institutions to address complex data needs. Climate TRACE exemplifies this by combining data from satellites, sensors, and other sources to track global greenhouse gas emissions, promoting climate action and accountability (Climate TRACE, 2021). The GeoAsset Project, led by the Centre for Global Finance and Innovation (CGFI), integrates geolocated asset data for environmental and financial analysis, facilitating sustainable investment and policy-making decisions (CGFI, 2022).

Conclusion

Discussion

- Mapping of the asset-level data landscape.
- Identification of critical gaps and challenges that hinder effective environmental risk assessment and adaptation planning.
- Insights into the need for improved data resolution, standardisation, and accessibility.

Findings

1. Tech is rapidly rising (plots dates/area)
2. NGOs are important (types of data gathering).
3. Prices become more available
4. Security concerns (need privacy)
5. Regional providers are improving (shifting to regional)
6. Reliability …. Accuracy here it is private, sector there it is still government structures.
7. Speak about

- Encouraging more open-access datasets
- Expand data collection in underrepresented sectors like water resources, healthcare, and urban development
- Further analyse geographic coverage and data collection methodologies could reveal additional gaps, especially in regions like the Global South.

Results

Different users require different spatial and temporal resolution of

Policy Level	Stakeholders	Frameworks	Asset-Level Data	Data Sources
High-Level Policy	Central banks, regulators, large investors, government ministries, international organizations, NGOs, advocacy groups.	TCFD, TNFD, NGFS	Aggregated data on populations, infrastructure, economic activities.	World Bank, UNEP, IPCC, NASA Earth Observing System, AI-driven climate models, fintech data platforms
Sector Adaptation & Resilience	Sector asset managers, insurers, regulators, NGOs	ISO 14090, Climate Bonds Initiative	Data on sector-specific infrastructure, economic activities, environmental services.	International Energy Agency (IEA), Carbon Disclosure Project (CDP), Sector-specific regulatory bodies, European Environment Agency (EEA), Geospatial AI, IoT sensors in industry, Fintech transaction data
Local Authority Policy	Local banks, insurers, asset managers, local governments, businesses, community organizations.	C40 Cities, ICLEI	Local data on community resources, infrastructure, environmental services.	Local government databases, Urban Climate Change Research Network (UCCRN), National Oceanic and Atmospheric Administration (NOAA), Regional GIS data providers, Geospatial AI, IoT urban sensors, Fintech credit data
Adaptation & Resilience Measures	Project financiers, asset managers, insurers, developers, construction firms, local governments, communities.	GCF, UNFCCC Adaptation Fund	Project-specific data on buildings, infrastructure, natural resources.	Environmental Impact Assessment (EIA) reports, Green Climate Fund (GCF) data repositories, Site-specific GIS data, Consultancy reports, AI-based environmental monitoring, IoT environmental sensors, Fintech investment data
Project Design	Project financiers, insurers, banks, engineers, construction firms, local governments, regulators	LEED, BREEAM	Detailed data on buildings, infrastructure, site conditions.	Engineering firm databases, Construction and maintenance logs, LEED and BREEAM certification databases, Site-specific hazard assessments (e.g., FEMA flood maps), Geospatial AI, IoT construction sensors, Fintech insurance data

Discussion