Advancing Role of Geospatial Knowledge Infrastructure in World Economy, Society, and Environment

Introduction

The 'Geospatial Way' is the future. It is the most efficient and effective way to collect, process, integrate and utilize information for overall global, national and individual development. Geospatial Knowledge is the result, enabling us to identify, contextualize and understand the many challenges and opportunities facing society within a geographic context. However, realizing the potential of this future state, particularly for developing countries, requires three key enablers – partnerships, knowledge sharing and capacity building. Therefore, with the objective to project the value proposition of Geospatial Knowledge, forecast its relevance and connectivity with fundamentals of next generation economy and society and to redefine the role of stakeholders: government, industry and civil society, the project on Advancing Role of Geospatial Knowledge Infrastructure (GKI) in World Economy, Society and Environment was launched in January 2020. Over the three phases of the project, a global partnership developed the concepts of and a blueprint for a GKI. The aim of this paper is to set out this concept of GKI based on the project outcomes and its relationship with other global geospatial developments for more feedback from the stakeholders.

Case for Change - Why is GKI Necessary?

The geospatial ecosystem is changing. Over a period of time, the concept of mapping agencies, government data and technology providers are moving on beyond traditional mapping. In real life it can be observed that geospatial is used everywhere and for a range of different uses. In this changing world most of these users have evolved from what were present in the past, for example geospatial technology is used to predict movements in financial market. There are a whole new range of users in this digital environment. Hence there is a need for an enhanced digital geospatial infrastructure to cater to these evolving user needs. It is imperative to move beyond current human-in-the-loop data-centric geospatial infrastructures, as data is not the endpoint. Knowledge, decisions, services, satisfaction are the value chain that data feeds. Knowledge, not data directly creates value. If data is 'the new oil', knowledge is perhaps 'the new capital'.

Most of the focus on geospatial by governments has been on delivering and 'opening – up' government geospatial data, providing a 'create once, use many' ecosystem, and making geospatial data and information accessible to all. In many jurisdictions, National Spatial Data Infrastructures (NSDIs) have delivered significant local, national and regional benefits. In others, they have not proceeded beyond an intent. But NSDIs are essentially a data infrastructure in a knowledge environment. Progressive governments are now looking beyond accessible data to value-creation through knowledge in a 4IR world.

The 4IR is fundamentally changing the way in which people live and work. While the extent to which this 4IR will unfold and reshape the economic, social, cultural, and natural environments is not known, it is understood that the changes are unprecedented in terms of size, speed, and scope. The main drivers of this revolution include the development and rapid adoption of technologies such as increasing storage and computing power; high speed communication networks; all kinds of sensors in an expanding Internet of Things (IoT); pervasive computing (also on smart phones); varying satellite

constellations of low, medium and high earth orbits and variety of sensors; and artificial intelligence/machine learning (AI/ML). The resulting interconnectedness of people, devices, and information, anytime and anywhere, raises the importance of geospatial information. 4IR technology and innovation are driving new business models and a new 'knowledge economy', based upon data, applications/analytics and existing knowledge. From the smallest use cases to global challenges, geospatial is ubiquitous as a powerful integrator and as essential underpinning data.

Looking at the evolved user demand and need for solutions for global challenges, knowledge, not data directly, creates value. This transition from data to knowledge is enabled by 4IR technology, these 4IR technology increasingly enable knowledge to be generated 'automatically' improving decision making. Therefore the concept of **Geospatial Knowledge Infrastructure (GKI)** was developed with a vision for 'geospatial knowledge at the heart of tomorrow's sustainable digital society, where knowledge, rather than data, is the focus. GKI goes beyond data and bespoke geospatial infrastructure to the enablement of user-focused decisions, automation and knowledge on demand in a broad digital ecosystem. GKI moves the geospatial ecosystem closer to users, generating greater value. It is a journey that seeks to benefit people and the planet by driving inclusive growth, sustainable development and global well-being. It is a concept that will enable knowledge and autonomy.

The Future Geospatial Ecosystem

The traditional view of geospatial from 2D to 3D maps has advanced to more multidimensional geospatial infrastructure embracing concepts of spatial digital twins with immersive interaction of twins through metaverse. New actors are emerging with the rapid integration of innovative frontier technology in the geospatial ecosystem, and the democratization of access to data. A futuristic national geospatial ecosystem needs to include all these stakeholders from far and beyond the geospatial community, including vertical/economic sector stakeholders, and information and communication technology (ICT) stakeholders and citizens.

The future geospatial ecosystem goes beyond knowledge to wisdom – transitioning from knowledge to 'applied knowledge' or 'applied intelligence' for impactful value-creation. The future geospatial ecosystem will thus be far wider and intelligent than ever before, moving beyond the realms of predictive analysis (insight and foresight) to prescriptive and adaptive and autonomous analysis. Core to the evolution of the future geospatial ecosystem would be synergizing people, processes, policies and strategies, and technologies to transform knowledge into wisdom to utilize the ecosystem to adequately address significant global, national, and local challenges.

The future geospatial ecosystem embraces the innovations happening in the geospatial space with regards to new geospatial data sources, as well as the innovations in the digital economy, and work in coordination with the technology innovations, while also addressing privacy, ownership, and interoperability concerns associated with the innovation and collaboration. In order to cater to the evolving user base beyond the geospatial experts, workflow integration of geospatial knowledge across user sectors is required, which can be made possible through automated analysis of near real-time geospatial data, which can enable intelligent decision-making. Agile multi-stakeholder collaboration is key for the success of the future geospatial ecosystem, which can be enabled by the realignment and evolution of industry business models based on user demand. The future geospatial ecosystem will be driven by strategic national development priorities in alignment with SDGs defined under the 2030 agenda[1].

[1] UN-GGIM Discussion Paper on Future National Geospatial Ecosystem

The collaborative project on GKI will act as a stepping stone towards the future geospatial ecosystem by enabling the development of an ecosystem of ecosystems consisting of stakeholders from and beyond the traditional geospatial ecosystem to make geospatial knowledge accessible for use cases across diverse sectors.

What is Geospatial Knowledge Infrastructure?

"We don't know when the next epidemic will strike, but I believe we can protect ourselves if we invest in better tools, a more effective early detection system, and a more robust global response system… There are also some interesting advances that leverage the power of computing to help predict where pandemics are likely to emerge and model different approaches to preventing or containing them." (Bill Gates, April 27, 2018)

GKI provides **a blueprint to integrate digital economies, societies and citizens with geospatial approaches, data and technologies and, in so doing, deliver the location-based knowledge, services and automation expected in this 4IR digital age**. It is a concept that supports Bill Gates' statement by moving today's geospatial ecosystem along the value chain towards knowledge, the answers to user challenges, and breaking out from the current focus on data infrastructures to knowledge infrastructures. GKI is not just about geospatial knowledge today, it is about readiness for the future. It is a direction of travel: from data to knowledge.

GKI embraces **8 principles** to support the enablement of knowledge through future geospatial infrastructures:

- **Knowledge is the focus**. Humans and machines seek knowledge to make decisions.
- Geospatial technology and data should integrate with established and emerging wider digital infrastructures and data to be a **unified geo-digital ecosystem**.
- **Predictive**. Be it in milliseconds or years, outcomes move from insight to intelligent foresight. Time and place are powerful contributions to prediction, integrated with many non-geospatial inputs.
- Normally **led by users** knowledge needs, not data and applications available.
- **Decentralized.** The web is naturally decentralized, with data and application value-chains becoming more complex across wider ranges of partnerships. Findable, Accessible, Interoperable and Reusable applications and data, for human and machine, are critical to this principle
- **Collaborative solutions**. To effectively meet societies' global sustainability challenges, including the digital divide.

- **Agility** is inbuilt. Innovative, dynamic and agile solutions are far better able to respond to global challenges, technology change and people's expectations in a rapidly developing world.
- Take **achievable actions now and then scale**; success cannot be achieved overnight.

To support nations and organisations apply these principles to their digital and geospatial infrastructures, GKI considers an integrated set of six elements and associated guidelines to support growing maturity. These elements are shown in Figure 1. A maturity matrix will be included in the GKI Project final report.

Figure 1. The six elements of a geospatial knowledge infrastructure (GKI)

Integrated Policy Framework

Governments will increasingly work to enable and regulate the development of a knowledge economy and society. Knowledge sits in no one domain; alignment and integration of policies across government departments maximizes national benefit and provide clarity to all. This alignment is particularly the case for digital, space, science, geospatial, environmental and business policies and strategies, which together will establish an integrated location approach for improved government policy making, services and industry to deliver social and economic benefits. In moving up the value chain towards knowledge, an Integrated Policy Framework includes:

- A national geospatial knowledge strategy, which could be part of a wider geo-digital strategy, standalone, or a United Nations Integrated Geospatial Information Framework (UN-IGIF) country-level action plan that considers knowledge as an objective.
- Policies and standards that enable Known Quality, Findable, Accessible, Interoperable and Re-useable (QFAIR) foundation data and applications for machines and humans, including standards, accessibility and open data.
- Aligned and coherent national digital and digital infrastructure, AI, space, EO, science, environmental and business policies and strategies (and in some case law). Associated policies on data security, data protection and privacy are based on outcomes not inputs.
- Departments that ensure that wider digital and geospatial policies are considered when preparing sector specific policies, maximizing existing national resources. Topically, this includes emerging policies that cover safe air/land autonomous vehicle operations.
- A national positioning, navigation and time policy and, where necessary, strategy.
- Based on user needs and resilience, and collaborating with industry and academia, government national digital policies enable the establishment of interoperable digital twins, enable digital innovation and increase the economic, social and environmental benefits of geospatially enabled knowledge.
- Digital governance, including geospatial governance, is considered holistically in government, with data and infrastructure in the same governance structure.
- Education policies bring geospatial understanding into AI, data and digital courses and across courses supporting key use sectors – from school through to post-graduate.
- Nations liberalize partnership policies better to enable industry to partner with government to deliver government digital services.
- Ultimately, Governments create an integrated knowledge policy framework that establishes the sustainable infrastructure for a digital economy and society that utilizes location.

Together, these improve integrated, evidence-based government policies and services, establish frameworks that maximise the benefits of geospatial knowledge to nations, maximise the value of a digital infrastructure and economy and create the resilience necessary for crisis.

Foundation Data

New data-hungry and digitally driven technologies operate in a complex world. There is just too much information for humans to process; technologies that make sense of the world and predict changes, are vital. Trusted and authoritative foundation data is an essential element of national infrastructure. It includes (1) the geodetic reference frame upon which position and height are referenced, (2) continuously updated machine and human QFAIR fundamental geospatial data and metadata, including High-Definition mapping and access to earth observation and (3) allied data sets (national spatial data sets not considered fundamental geospatial data by the United Nations such as meteorology). Together with analytics, these enable nations, businesses, citizens and machines to derive the knowledge they seek to solve problems, exploit opportunities, and deliver new value. Equally, assured or authoritative foundation data provides greater trust in knowledge-based digital outcomes. Moving up the value chain towards knowledge, Foundation Data includes:

- Foundation data agencies that reach into client sectors to understand use cases and base data, service and knowledge services based on current and emerging requirements.
- Government designated authoritative data, with known provenance, quality and currency that help overcome uncertainty and risk, as part of the national infrastructure.
- Efficient access to earth observation data services in time of peace and guaranteed in times of trouble.
- Government mandated system of persistent, consistent, and unique identifiers across registries and government databases to enable integration.
- Based on current and emerging requirements, holistic nationally defined geospatial information management arrangements and sensor mix, drawing upon global, government and industry systems, and where necessary national systems. Government does not replicate when industry is sustainably meeting use cases.
- Agencies may develop through product-centric, data-centric, solution-centric to knowledge-centric outputs. Nations coherently capitalise on AI, EO and other sensors, cloud and high-performance computing to facilitate autonomously delivered continuously maintained and integrated data from many sources and offer knowledge services where there is a public task requirement.

Together these enable governments to deliver foundation data as part of national digital infrastructure and geospatial agencies, utilising 4IR technologies, to meet user requirements including for QFAIR continuously updated authoritative data.

Partnerships and Collaborations

Given rapid technological change and the increasing sources of data and analytics across the private sector and academia, partnerships and collaborations will be increasingly common in co-creating value in data and knowledge. Costs and benefits will be shared across the value-chain, which crosses government, industry and citizens. New partnerships will emerge - be they ad hoc collaborations to solve singular challenges, long-term business partnerships servicing a user sector or public-private knowledge co-creation partnerships. Partnerships and collaboration are already happening in some countries between companies within sectors and between businesses, academia and government

innovation programs, but not typically between sectors and public private partnerships (PPPs) have barely touched the geospatial ecosystem. This element includes the important partnership with citizens, both as users and data providers, especially as citizens gain more rights to data about them and their location. In moving up the value chain towards knowledge, Partnerships and Collaborations includes:

- A national geo-digital knowledge enterprise. This derives cross-government user-focused future geospatial knowledge requirements arrangements and includes government and industry players across the future geospatial and digital ecosystems. It funds pilots and research and includes geospatial accelerators and innovation.
- The refocus of industry bodies from data collection to data and knowledge management reflected also in professional development.
- National partnership with organisations such GEO, W3C and OGC as well as participation in UN GGIM global and regional committees of experts.
- Clear policy on citizens' voluntary contribution to national geospatial data, including industry-held citizen data.
- Laws that enable partnerships in a digital world where industry is leading much innovation and disruption and can help governments achieve national objectives at a reduced cost.
- Clear relationships established between the research community and industry to monetise geospatial knowledge research.

Together these enable widespread cross-sector geospatial knowledge engagement, industry-government partnerships and an innovative, collaborative, industry.

Industry Leadership[2]

Even if based on government-funded research, most innovation, autonomy and knowledge services will be delivered by industry faster than Governments can understand implications or act, therefore giving industry an increasing leadership role. With leadership comes social responsibility, a need to work with governments, institutions and citizens to help policy development and the development of appropriate skills. For global businesses these social responsibilities are global. Most major companies use geospatial technologies in work processes; new companies offering knowledge services to farmers, for example, have the potential to transform agricultural yields. Covid has chased the laggards (the construction industry, for example) into new thinking, although land administration technology opportunities are often hampered by policy and legal constraints. Industry is opening many other new opportunities: collecting and managing geospatial data fit for many uses at a fraction of the price, reducing emissions and spotting abnormal emissions to tackle climate change, dating applications, reducing banking fraud, the ability to tackle tough multi-facetted challenges, deliver eGovernment services, manage digital twins. Moving up the value chain towards effective industry leadership includes:

- Growing user sector industry associations understanding of geospatial knowledge and vice-versa (the key role of the World Geospatial Industry Council). This is both to increase the use of geospatial knowledge in economic sectors and for the core geospatial sector to embrace the growing geospatial ecosystems in each of those sectors.
- Digital industry involvement in policy making from a social good, as well as profits motivated, perspective and declaring this publicly.
- Increasing investment in geospatial research within sectors, by both government and industry.

[2] Industry in this context refers to the private sector, i.e. not a government agency.

- Investors in upstream Space sector to further consider investment in downstream knowledge solutions companies.
- Differential pricing of technologies, knowledge services and data to help overcome the geo-digital divide.
- Geospatial innovation and accelerator programmes will be created in nations or in partnerships between nations to support the development of geospatial start-ups, including the incorporation of geospatial expertise in wider digital innovation centres.
- Industry development of data trusts and similar mechanisms to help ensure fair reward across value chains.

Together these lead to increased social and economic benefits of geospatial knowledge capabilities across all industry sectors, with user-sector business processes adjusting to gain maximum value from geospatial knowledge.

Applications, Analytics and Modelling

In the same sense that foundation data is fundamental to geospatial knowledge, so too are the applications, analytics and modelling capabilities that consume data to produce information and knowledge, naturally incorporating location. This knowledge is essential for human and machine decision-making, including all automation. AI/ML is allowing vast swathes of remotely-sensed data from a multitude of sensors to be processed into information, creating insights (it is estimated that 100Tb of meteorological data is collected a day, for example). Algorithms can deliver elusive foresight based on the context of the question or use case, but this is a work in progress as few applications really enable prediction and, where they do, they are often constrained on available data, including foundation geospatial data, and greater confidence is often sought in the derived knowledge, especially in autonomy. But they do predict weather and flooding, help ensure automated vehicles avoid pedestrians, and target consumer marketing. Many open algorithms will sit alongside open data as part of the digital infrastructure and have to be QFAIR. In moving towards geospatial knowledge:

- Across government and industry, workflows will incorporate a variety of analytical and predictive techniques and multiple data sources, not exclusively geospatial.
- Industry (and whole geo-digital ecosystem) open with customers about the assumptions and bias within models, applications and analytics.
- Government and industry increase investment in relevant emerging technologies.
- Virtual testing systems for safety critical autonomous systems fully incorporate digital geospatial models from around the world.
- Open standards developed to allow visualization, augmented reality and virtual reality systems to be data agnostic.
- Location-based government online services that support citizen and business needs.
- Guidelines and standards for the use of location in applications will be developed to enable the veracity of derived knowledge to be expressed consistently.

Together these support the development of applications and models for knowledge economies.

Geospatial Dimension to the Wider Digital Ecosystem

Location is increasingly ubiquitous as a data attribute, geospatial and the use of the web and cloud is increasing, yet much geospatial information is not accessible from machine to machine. GKI integrates with and supports the geospatial dimension to the wider digital ecosystem through an open positioning infrastructure, machine-accessible geospatial information that can be seamlessly

integrated into sector workflows, standards, expertise, technologies, and analytics. The digital infrastructure should develop with location, geospatial data and geospatially enabled analytics at its core, a true geo-digital infrastructure. Web 3.0 will improve the environment that enables this. Moving up the value chain towards knowledge:

- Data providers use Open Geospatial Consortium Tier 3 and 4 standards and geospatial standards organisations fully engage with W3C and similar organisations to develop Tier 4 standards.
- Enact knowledge on demand through data access that includes globally persistent URIs for Spatial Things, spatial data indexable by search engines, API and linked data.
- Employers recruit and develop talent from across society to bring diversity in thinking, bias reduction and to make most of scarce talent.
- Geospatial education and professional development adapt for the broader geo-digital ecosystem and lift digital skills within the workforce.
- Governments and businesses better understand the economics of geospatial knowledge.

Together these aim to embed geospatial technologies and data within digital infrastructures, including the internet.

Relationship Between GKI and Other Global Geospatial Developments

Where implemented, spatial data infrastructures (SDI) have helped share geospatial data across government communities but conventional SDI would benefit from further development to support users in a knowledge environment. GKI offers this further development. The European Union with its INSPIRE directive is developing its future thinking with its European Union Location Framework, that, where concepts overlap, has a substantially degree of alignment with GKI.

In parallel over the last 3 years the UN has examined the Future Geospatial Ecosystem. GKI thinking has been included in this. GKI is seen as part of this ecosystem whilst is also proposed as an engine to help power the ecosystem.

The United Nations successfully launched the UN-IGIF to help countries develop integrated geospatial information infrastructures that meet national needs. This framework is in widespread use globally as governments develop action plans for their future geospatial information infrastructures. Because GKI focuses on user sector knowledge generation, which is anchored by geospatial information, GKI reaches beyond governments into industry, the wider digital ecosystem and the applications community. However, UN-IGIF country-level action plans provide much of the foundation data element of GKI along with associated geospatial information policies and partnerships. GKI needs nations to build sustainable foundation data capabilities and thus is reliant on the IGIF. Likewise, a nation seeking a more user-sector knowledge focussed UN-IGIF country-level action plan could consider relevant GKI guidelines as it uses the UN-IGIF. This is illustrated in Figure 2.

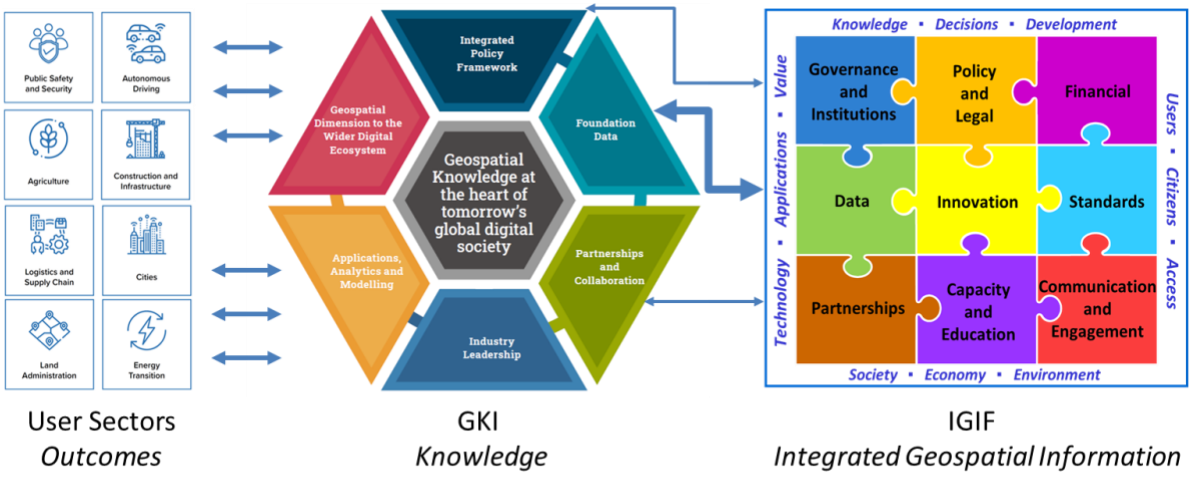

Figure 2. The relationship between GKI and the UN-IGIF is demonstrated.

GKI Integration in Sectoral Workflows

With GKI aiming to place geospatial at the heart of tomorrow's sustainable digital society, there is a need to ensure that geospatial data and knowledge play a central role in use cases across sectoral workflows. Different sectors are at varying stages of geospatial knowledge adoption in their workflows. The level of adoption in a particular sectoral workflow in a country also depends on where the sector is placed in the list of development priorities of the country. The integration of GKI elements can help in enhancing the knowledge adoption and integration, and thereby better decision-making in sectoral workflows. Ultimately, enhanced geospatial adoption across sectoral workflows will enhance the efficiency of the functions in the workflow, and improve the sectoral output, thereby increasing the sectoral contribution towards national development. The section describes the integration of GKI elements and its impact on the workflows of 2 sectors – agriculture and energy transition.

Agriculture

Agriculture is a critical sector as it impacts social, economic and political equations globally. Sustainable agriculture is the basis for a strong and powerful economy since it addresses the requirements of society. The sector faces a major challenge of increasing agricultural productivity to meet the increasing global demand. Since land and water are two of the major resources associated with the sector, the deteriorating quality of land, and increasing water stress pose a threat to the agricultural and food systems. In addition, climate change and the intensification of natural hazards test the resilience of the systems further. Efficient management of agricultural workflow through technology adoption, aided by cohesive regulatory frameworks are thus crucial for enhancing the productivity of the sector, and to address the evolving challenges.

Geospatial technology enables extraction of hidden spatial relationships in large and diversified datasets, thereby leading to a better understanding of the sector and helping with policy-making and policy compliance. The agriculture sector broadly includes five phases input, production & cultivation, harvesting & processing, storage and distribution. Proper coordination across all these phases ensures cost saving and reduced time overruns. Integration of GKI elements across the sectoral workflow has several benefits. First phase of the workflow is input, which includes all resources involved in

producing farm commodities. GKI provides greater analytical support for precision farming which enables farmers to effectively use crop inputs including fertilizers, pesticides, tillage and irrigation water. More effective use of inputs means greater crop yield and quality, without polluting the environment.

GKI encourage predictive analytics by integrating frontier technologies like Artificial Intelligence and Machine Learning with geospatial data which enable farmers to quickly and accurately predict yields, before crops are harvested. With accurate yields, farmers are able to find buyers for all of their harvest, thereby eliminating food wastage and increasing profits. This also supports the financial sector futures and insurance markets. It further enables real-time insights into field conditions, allowing farmers to be proactive. It also enables timely detection of crop diseases, supporting efficient farm monitoring during the production and cultivation phase of the sector workflow. GKI leverages many new opportunities enabled by 4IR. It accelerates farm automation and knowledge-on-demand. Agricultural robots assist farmers using digital twin of farms in fruit-picking, harvesting, planting, transplanting, spraying, seeding and weeding, thereby reducing in human workforce and improving farm operational efficiency.

GKI supports improved, integrated, evidence-based government policies and services. Government policies to release data and bringing data together from various sources will allow the private sector to create, and maintain geospatial infrastructure, innovations and process improvements to provide applications to farmers. These applications will help farmers manage their farms more efficiently by providing real-time information on weather conditions, soil quality and crop management.

GKI integrates with and supports a geospatial dimension to the wider digital ecosystem. Digital technologies like internet, mobile technology and devices, digitally delivered services and apps, cloud and service platforms are changing agriculture and the food system. Traceability technologies and digital logistics services offer the potential to streamline agri-food supply chains, while also providing trusted information for consumers. These technological advances can support the goal of achieving more resilient, productive, and sustainable agriculture and food systems, which better meet consumer needs.

Energy Transition

Energy lies at the heart of other sectors of the economy. The increasing number of extreme events calls for rapid action to mitigate climate change, and energy transition lies at the heart of climate change mitigation. Energy transition involves the accelerated deployment of energy efficiency and renewable energy technologies. This requires systemic innovation, matching and leveraging synergies in innovations across all sectors and components of the system, and involving all actors. However the energy transition is hindered by systemic challenges like high cost of renewable energy technologies, regulatory uncertainty, grid flexibility requirements, data in silos, etc.

The rising global demand for energy, which goes hand-in-hand with the global commitments for carbon neutrality, necessitates the incorporation and integration of modern digital technology and associated business models in order to facilitate an effective energy transition. The sixth assessment report by the United Nations' Intergovernmental Panel on Climate Change (IPCC) identifies digital technology as a key factor in mitigating climate change, and especially in facilitating energy transition. The adoption and integration of geospatial technologies across the energy transition workflow is a key component of this digital transformation. Geospatial Knowledge Infrastructure can provide the

framework for enhanced integration of geospatial and digital technologies in the energy transition workflow.

The integration of geospatial technology and frontier technology like AI/ ML can help in minimizing the environmental footprint of the traditional energy industry through the monitoring of greenhouse gas emissions. Global collaborative initiatives like Climate TRACE harness remote sensing and AI to track greenhouse gas emissions by the energy sector among other sectors, and make it available openly to the public to enable energy transition. But the targets of carbon neutrality can only be met through a systemic change with transition to renewable energy sources. The transition to renewable energy encompasses the aspects of infrastructure planning and development, infrastructure operation and maintenance, and energy generation and distribution. The pace of technology development is faster than regulations, and the absence of comprehensive regulations can hold back both investment and utilization. Hence, it is imperative that geospatial and digital technology adoption is encouraged through its integration in energy transition policies and strategies thereby ensuring that regulatory gaps are avoided.

Renewable energy infrastructure planning and development involves the identification of ideal location, which includes aggregation of data from different systems like weather station surveillance, digital elevation models (DEMs), as well as data on ancillary infrastructure like existing grid, roads, railways, etc. The planning is thus dependent on the availability of authoritative foundation geospatial data on the geography and infrastructure which is made available by geospatial agencies and the industry. The geospatial industry can assist the energy stakeholders in data collection and providing the required data, which complements and enhances the foundation data. The location identification is also accompanied by energy demand modelling based on parameters like socio-economic factors, population density, historical energy consumption etc. The infrastructure planning and design thus involves integration of spatial and non-spatial data from diverse sources, which necessitates the implementation of common standards which ensure interoperability.

Adopting integrated geospatial and digital solutions helps enhance the operation and management of renewable energy infrastructure by enabling remote operations, workforce management, etc. thereby improving the return on investment. Geospatial data from UAVs and sensors can help detect exact issues in the infrastructure, whose occurrence can also be predicted in advance using AI, which can help in proactive maintenance. The operation and maintenance of the infrastructure can be enhanced through the adoption and utilization of bespoke solutions developed by or in collaboration with geospatial and digital industry. With renewable power sources becoming more prevalent, the energy system is becoming more complex and distributed, with consumers also becoming small-scale energy producers. The increase in complexity raises fresh challenges related to management of local microgrids, predicting demand, ensuring energy storage and grid capacity, etc., which can be addressed through Smart Grids powered by geospatial and frontier technology. Interoperability is key to the functioning of smart grids, due to the integration of data from diverse renewable energy sources. Hence it is imperative that there is close cooperation among the diverse stakeholders, and common standards are developed for better management of these resources. Network-based geospatial solutions enable utilities and other stakeholders to model network connectivity of transmission and distribution assets including distributed generation like solar and wind farms, and also automate fault location, isolation and restoration mechanisms to increase the reliability of the network. Geospatial knowledge also enables the consumers of renewable energy by helping them identify the energy source which is most beneficial and efficient for their specific use cases.

In addition to the aforementioned sectors, the impact of geospatial knowledge integration in the workflows of six other sectors – construction and infrastructure, logistics and supply chain, cities, land administration, public safety and security, and autonomous driving – were also analyzed as part of the GKI project. GKI integration in the construction and infrastructure workflow can support digitalization and enable greater control over project management through improved information management and geospatial knowledge-enabled decision-making, thereby enabling cutting down on cost and time over-runs, and completion of projects within the specified budgets and timelines. In the logistics and supply chain sector, GKI integration can enable adoption of shared economy business models, prediction of future demand, and drafting better responses to evolving consumer demand, thereby delivering enhanced services to the consumers. In the Cities sector, GKI can enable greater control over complex processes and systems across various verticals in city planning, development, operations and maintenance through integration of datasets from the verticals using common standards, and providing knowledge in accessible formats to city government officials and citizens.

In the Public Safety and Security sector, predictive and prescriptive analytics enabled by GKI integration can lead to real-time situational awareness, while not compromising on data security and privacy through enhanced integrated regulations. GKI integration in the autonomous driving sector can lead to better sharing of data between the sectoral stakeholders and governments, and enhanced integration and interoperability of autonomous driving data with allied data sources for the development of better infrastructure supporting autonomous vehicles of the future. GKI integration in the land administration workflow can support fit-for-purpose land administration by opening the doors for enhanced collaboration with private sector for better understanding of evolving user demands, and thereby developing fit-for-purpose knowledge solutions to enable decision-making. GKI can thus enable better adoption and integration of geospatial and frontier technology in sectoral workflows in collaboration with the geospatial, digital, and user industry for knowledge creation, leading to better sectoral outputs and improved user experience. Detailed outlook on GKI integration in all 8 shortlisted sectors along with analysis of its impact will be included as part of the GKI final report.

Impact of GKI on National Geospatial Information Agencies

In all nations there are examples of geospatial knowledge making a difference in user sectors although often without national geospatial information agency involvement. Considerable global discussion is therefore taking place on the future of national geospatial information agencies. Some agencies are splitting out national regulator functions from geospatial data management, others are becoming brokers of authoritative geospatial data and others are driven by a need to offer solutions to specific users, with national datasets managed behind these solutions. There is no one answer as this is dependent upon national need and the national user-base. Thus, the GKI guidelines that national geospatial information agencies can employ will differ.

However, just as all technology businesses are transforming to remain relevant, transformation is equally essential for national geospatial information agencies. One common requirement is to become closer to national challenges and user sectors, thereby understanding the data, services and solutions gaps that need to be filled to meet user needs (government, industry, citizen, machine). There is then a need to embrace technology, processes and partners to meet user requirements.

Agencies may develop through product-centric, data-centric, solution-centric to knowledge-centric outputs, mindful of their part in the wider geo-digital ecosystem and with an eye to the future (the principle of agility). They may capitalise on AI, EO and other sensors, cloud and high-performance computing and partnerships and may integrate data from many sources, including private industry, in

their data management. As leaders, they are also likely to focus on steering national policies and strategies towards knowledge and may offer knowledge services where there is a public task requirement. However, the ultimate knowledge-centric goal under GKI is for national geospatial information agencies to facilitate autonomously delivered continuously maintained and integrated machine QFAIR data services for users.

The GKI final report will present a generic maturity model for national geospatial information agencies.

GKI – Progress and Way Ahead

Different countries around the world are at different levels of maturity with respect to the development of national geospatial infrastructure. The GKI readiness index provides an assessment framework, which equips the geospatial decision-makers and wider stakeholders in countries to gauge the maturity of various parameters enabling the holistic development of knowledge-focused national geospatial infrastructures. The assessment framework which is based on the 6 GKI elements provides actionable insights into critical factors of an integrated approach towards national geospatial infrastructure development.

Since GKI aims to place geospatial knowledge at the heart of the digital economy, it is imperative that geospatial policies/ strategies are in alignment and eventually integrated with digital and sectoral policies/ strategies. Countries around the world, including both developed and developing countries are adapting to the changes happening in the geospatial and wider digital ecosystems, and incorporating evolving concepts into their national policies or strategies, like the development of GKI strategy in Switzerland, and the inclusion of GKI under national geospatial policy in India. The leader countries as per the readiness index, are integrating geospatial and digital policies, with geospatial policy acting as a building block for digital transformation. The developing countries which are primarily focused on the development of country-level action plans based on IGIF, can complement their ongoing efforts by adopting a wider lens of geospatial integration in digital and sectoral policies to make their national geospatial infrastructures ready for the digital economy.

Trusted and authoritative foundation data is an essential element of any national infrastructure. The leader countries as per the readiness index have mature data infrastructure capacities, and provide high-scale and frequently updated foundation data across all fundamental data themes. These countries also have access to high resolution earth observation data, either through their own satellites, or through collaborative efforts. The less mature countries as per the readiness index are still in the process of updating their datasets to higher resolution and higher update frequency to meet the evolving demands. GKI can help the countries think and act beyond geospatial data in silos, and develop mechanisms to enable enhanced integration of geospatial data with non-spatial data for meeting the evolving demands.

The leader countries are also involved in and are active participants in international geospatial collaboration initiatives like UNGGIM, GEO, OGC, etc. In addition, they are also engaged in collaborations with the private industry at the national level at different phases of the geospatial knowledge production workflow including data collection, analysis, application development, etc. The level of collaboration is also influenced by the capacity of the industry at the national level. In the leader countries the private geospatial industry is focused more on the development of hardware, software, and solutions, whereas in the less mature countries, the industry is focused more on the provision of data collection, updating, integration services, etc. The industry in the leader countries are also supported by strong dedicated incubation and accelerator programs for geospatial start-ups.

The developing countries are making efforts to develop their local industry through the passing of policies/ strategies which help democratize geospatial data and enhance industry development.

Data integration, analytics, modeling and applications are the engines of digital growth, knowledge on-demand, and improved decision-making. The leader countries have advanced technology architectures for geospatial data and knowledge dissemination, complemented by robust financing of emerging technologies, which enable enhanced geospatial adoption across user sectors. Whereas the lack of an established IT infrastructure, along with lack of capacity and awareness hinder geospatial adoption in less mature countries as per the readiness index. Greater level of technology adoption, can be achieved by building collaborative approaches between the government and industry, investing in infrastructure and education and skill building, etc.

Geospatial data and applications are part of the global digital infrastructure. The leader countries are among the most technologically advanced nations, and also stand out as being innovative and dynamic economies, which aid in better integration of geospatial-enabled knowledge in their digital infrastructures. The geospatial dimension to the digital infrastructure in these countries are also enhanced through enhanced interoperability between spatial and non-spatial data enabled by adoption of common standards, along with up-skilling programs within the government and private industry to make the workforce ready to meet the increasing demand across sectors for geospatial-enabled knowledge. Many of the developing countries are focusing on the development of Spatial Data Infrastructures in their countries, and GKI can help them think beyond SDIs towards enhanced integration of spatial and non-spatial data through integrated standards, and making knowledge accessible to wider sections of society through digital platforms. In addition to the national efforts, global standards community across the geospatial, digital, and user domains, including organizations like OGC, W3C, ISO, etc., can contribute by collaborating and working together for the development of integrated standards which make real-time geospatial knowledge available for diverse users across domains over the web and in applications, in accessible formats.

***Kindly share your inputs on the document on the email addresses below:**

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