

The Geophysical Sustainability Atlas: Mapping geophysics to the UN Sustainable Development Goals



Maria A. Capello¹, Anna Shaughnessy², and Emer Caslin³

<https://doi.org/10.1190/tle40010010.1>

Abstract

Geophysics is enhanced if the value it adds to society, economic systems, and the environment is assessed, understood, and communicated. A clear value proposition can inspire new generations of scientists to pursue careers in geophysics and motivate current geophysicists to expand their activities and utilize their skills in ways that could enable their long-term employability or entrepreneurship. One way to position geophysics and geophysicists as value creators is to map geophysical applications and practices to the 17 Sustainable Development Goals (SDGs) adopted by the United Nations in 2015. A Geophysical Sustainability Atlas was developed to illustrate how geophysics contributes to each of the SDGs and to provide examples of specific applications and collaboration strategies. The atlas aims to facilitate an understanding of the value geophysics brings toward achieving each SDG, providing geophysicists and stakeholders with a sense of being frontline contributors in the pursuit of these objectives and, at the same time, providing a visualization of current and future opportunities related to the sustainability of our world and our profession.

Introduction

The outlook for geophysics would be brighter if there were greater clarity about how the science is applied or can be applied to societal, economic, and environmental challenges. We created the Geophysical Sustainability Atlas to map various ways the science can be practiced and applied to deliver value to the world in the context of the 17 United Nations (UN) Sustainable Development Goals (SDGs) (United Nations, n.d.). In so doing, we aimed to create a platform to promote better understanding and inspiration about sustainability in geophysics.

We took motivation from a similar atlas produced by IPIECA, the global oil and gas industry association for environmental and social issues formerly known as the International Petroleum Industry and Environmental Conservation Association (IPIECA et al., 2017). From that energy industry-focused mapping exercise, we extracted elements that relate to geophysics and expanded them as we mapped technologies, practices, and applications specific to the SDGs.

A fundamental premise grounding the creation of the Geophysical Sustainability Atlas is that geophysics and geophysicists need a compelling story to support their attachment to collaborative efforts pertinent to the SDGs and their main interdependent components focused on scientific, economic, and environmental problems. The aim is to create a shared vision among stakeholders in geophysics about how to enhance the

science's value in all components of its practice, including research and development, entrepreneurship, business operations, academia, and humanitarian engagement.

The Geophysical Sustainability Atlas should evolve as its use grows and feedback is received. The hope is that this atlas will trigger actions that positively impact the future of geophysicists and their integration into global sustainability pursuits.

The UN SDGs

The 17 UN SDGs (Figure 1) represent one of the most forward-looking collaborative efforts embraced by a multilateral organization. The UN adopted the SDGs in 2015, with a target completion date of 2030. The UN describes the goals in this way: "The Sustainable Development Goals are the blueprint to achieve a better and more sustainable future for all. They address the global challenges we face, including poverty, inequality, climate change, environmental degradation, peace and justice" (United Nations, n.d.). The SDGs, supported with a remarkable communication campaign, are challenging, yet there is optimism and encouragement in this frame, as they provide strong guidance around which major global entities can focus their activities.

All UN member nations adopted the SDGs as a universal call to action to improve the quality of life for everyone on the planet. As global citizens, geophysicists have a responsibility to respond to these goals. The mapping of geophysics to the SDGs seeks to serve two objectives:

- 1) to establish a sense of belonging for individuals and organizations working in geophysics about their participation in and relevance to the 17 SDGs
- 2) to raise awareness about steps and conditions that should be implemented by individuals and organizations in geophysics so they can remain relevant in the long term, serving society and preserving the planet

We have noticed that many professionals working in geophysics only recently have become aware of or knowledgeable about the SDGs, which would indicate that even the best communication campaign, anchored in the most noble causes and appealing graphic designs, requires years to percolate into day-to-day activities and interests.

The 17 SDGs are tightly interconnected and shape a decisive call for action by all countries — poor, rich, and middle income — to stimulate prosperity while protecting the planet. The unexpected COVID-19 pandemic has demonstrated how interconnected

¹Red Tree Consulting, Houston, Texas, USA. E-mail: mariangelacapello@gmail.com.

²SEG president-elect, Boston, Massachusetts, USA. E-mail: anna@interp3.com.

³Schlumberger, Belfast, Northern Ireland, UK. E-mail: ecaslin@slb.com.



Figure 1. UN SDGs for 2030.

we are, and must be, to fight and prevent catastrophes of several kinds. Geophysicists have an important role to play in society tackling all 17 SDGs (Figure 2), a notion that is not only motivational but engaging.

Mapping geophysics to the SDGs

Many organizations have conducted mapping exercises to align their sustainability plans, goals, and performance measurements with the SDGs. Most notably, several organizations that are tied to or are an integral part of the UN, such as the Food and Agriculture Organization of the United Nations and the United Nations Educational, Scientific, and Cultural Organization (UNESCO), along with a number of national and international companies related to geophysics have conducted these mapping exercises to highlight how they are advancing the SDGs in their internal and external activities, ingraining them in their strategies and activities, and communicating results accordingly.

By performing an SDG mapping exercise, an organization, an industry, a scientific sector, or a segment of society can better identify its opportunities, strengths, and weaknesses as a potential contributor to the achievement of these goals. The results also will empower individual geophysicists to identify opportunities to contribute toward advancing the SDGs in their own spheres of influence and expertise. Mapping exercises are a way to build individual and organizational strategies for a new era, creating a buy-in toward the SDGs.

Creation of the Geophysical Sustainability Atlas was grounded in our assessment of the applicability of geophysics to all the SDGs, incorporating specifics of the geophysics profession as well as both basic and applied subdiscipline activities, education, and research in a thorough process aimed to include all sectors of geophysics and achieve inclusiveness.

A step process was followed to establish relationships between the geosciences and each of the SDGs and to gain the buy-in of key stakeholders in geophysics (Figure 3).

The ultimate aim is that all stakeholders gain a heightened awareness of the benefits that would derive from strengthening ties between geophysics and pursuit of the SDGs. Geophysics contributes to all SDGs and has the potential to contribute even more when used in collaboration with other disciplines. After the atlas was drafted, a series of processes was implemented to validate the mapping of geophysics to the SDGs. These comprised conducting focus groups and other meetings in various areas of geophysics, including mining, near surface, satellite recognition, seismology, and humanitarian applications. In addition, we researched mapping work conducted in other industries.

Focus groups of subject-matter experts (SMEs) were formed to assess the work done, provide critique, and endorse the validity of our assumptions and recommendations. The SMEs were from academia, research, education, industry, and humanitarian sectors and were assembled into three groups to examine the mapping work involving SDGs related to their areas of expertise. All three groups also examined the work related to what were referred to as “transversal SDGs,” those SDGs that touched all three areas.

- **Focus group 1 — Academia, research, and education** (SDG 4, 9, 14, and 15): This group focused on knowledge transfer and upskilling, mainly aimed at research and education.
- **Focus group 2 — Humanitarian** (SDG 1, 2, 6, and 11): This group envisaged how geophysics supports objectives related to humanitarian pursuits such as water resource management and disaster risk response to mitigate the impacts of natural disasters such as earthquakes, tsunamis, volcanoes, and infrastructure failures.

- **Focus group 3—Industry** (SDG 3, 7, 13, and 16): This group aimed to analyze how industry uses geophysical tools and techniques for responsible exploration and production of the earth’s natural resources such as oil, gas, minerals, and soil, among others.
- **Transversal (common to all focus groups)** (SDG 5, 8, 10, 12, and 17): These SDGs were considered applicable to a variety of segments of geophysics and were included in the analysis and brainstorming of all focus groups.

After sharing the drafted mapping with these groups, specific meetings were organized for each group to discuss and provide feedback. In addition to meetings, two other discussion sessions were conducted — one to gather feedback from

geophysicists involved in mining and another to acquire insights from contractors and entrepreneurs, which included leaders of the International Association of Geophysical Contractors (IAGC). All SDGs are intrinsically interrelated, and this naturally surfaced in the findings and summaries extracted from the focus groups.

The relationships identified between geophysics and each SDG were summarized and are presented in three separate titles in the following pages:

- **Mapping of geophysics to the SDG** — examples of how geophysical programs can support that SDG
- **Collaboration and expansion opportunities** — examples of how to further the applicability and teamwork among sectors



Figure 2. UN SDG official descriptions. (United Nations, n.d.)

or organizations to expand support to that specific SDG

- **Geophysical enablers** — a representative selection of methods or technologies that can be applied toward achievement of the SDG, provided only as meaningful examples and not as an exhaustive compilation

As indicated throughout the mapping, collaboration among geophysicists is essential for the discipline to make meaningful contributions to the goals by the United Nations' target date of 2030.

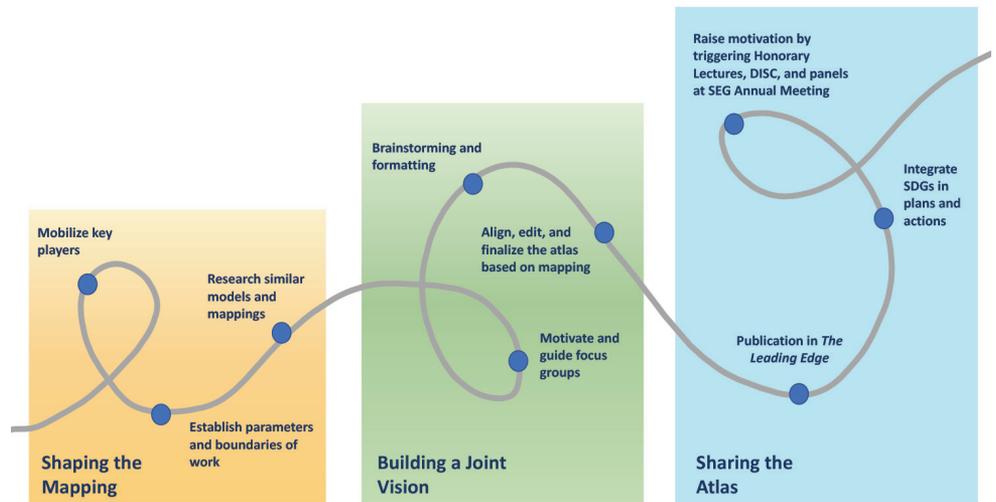


Figure 3. The Geophysical Sustainability Atlas mapping process.

The Geophysical Sustainability Atlas



Mapping geophysics to SDG 1 — End poverty in all its forms everywhere

- 1) Increase geophysical monitoring to reduce the vulnerability of communities to natural disasters (earthquakes, tsunamis, etc.), climate-related events (flooding, landslides, etc.), and poor industry practices (induced seismicity, toxic materials, etc.).
- 2) Use geophysics for the sustainable management and development of the earth's mineral, water, and energy resources, facilitating increased access to them.

- 3) Optimize the exploration, production, and utilization of resources in a sustainable manner, ensuring minimal environmental, cultural, and social impact.

Collaboration and expansion opportunities

- Highlight the central role geophysics plays in sustaining life on earth and communicate this to the public, governments, media, and educational institutions.
- Increase the participation of local talent and workforce in geophysical operations, ensuring knowledge and skills are transferable to uplift social and economic development.

Geophysical enablers

- passive and active seismic reflection and refraction
- electric and electromagnetic techniques
- near-surface techniques
- earthquake seismology
- borehole geophysics
- reservoir characterization
- gravimetry
- magnetometry



Mapping geophysics to SDG 2 — End hunger, achieve food security and improved nutrition, and promote sustainable agriculture

- 1) Apply geophysical techniques to find local water resources to enable enhanced crop production and reduce farming costs.
- 2) Perform soil property mapping to assess salinity, compaction, and moisture level to increase agricultural productivity capacity.
- 3) Monitor water quality, availability, disposal, and pollution for agricultural purposes.
- 4) Assist with managing resources transparently.
- 5) Perform bathymetric mapping and benthic habitat assessments to build fish-conservation strategies.
- 6) Minimize land usage during geophysical operations.

Collaboration and expansion opportunities

- Conduct risk-assessment studies to ensure availability of habitable land (flood-damage assessment, landslide-risk studies, detection of landmines and waste disposals).
- Train local communities in using geophysical tools for risk assessment and mitigation.

Geophysical enablers

- risk assessment and mitigation training in local communities
- echo sounding
- side-scan sonar
- ground-penetrating radar (GPR)
- electromagnetics
- resistivity
- electromagnetic radiation
- resistivity laser scans
- sonar
- seismic attributes
- amplitude variation with offset (AVO)
- gravity
- interferometric synthetic aperture radar (InSAR)

Mapping geophysics to SDG 3 — Ensure healthy lives and promote well-being for all at all ages

- 1) Use geophysical exploration tools to assess opportunities to replace coal and wood with cleaner fuels such as natural gas and renewables. Evidence links coal and wood emissions to ambient and indoor pollution that can impact respiratory and cardiovascular health.
- 2) Employ geophysical research and monitoring techniques to improve short- and long-term anticipation of natural hazards and climate-related events (earthquakes, volcanoes, tsunamis, landslides, and flooding).
- 3) Use geophysical techniques to detect, monitor, and mitigate air, water, and soil contamination.

Collaboration and expansion opportunities

- Ensure safe working conditions and health, safety, and environment (HSE) training of all individuals involved in geophysical activities, with adherence to HSE global best practices for employees, contractors, and communities.
- Provide training on assessment and monitoring of geohazards, conduct public-awareness campaigns on disaster risk response, help establish early-warning systems, contribute to the readiness of communities, and support policy development.
- Routinely address the social, ethical, and environmental implications of geophysical operations on local communities and incorporate these activities into project-management lifecycles.

Geophysical enablers

- electromagnetic profiling
- geoelectrical investigations
- electrical resistivity
- tomography
- induced polarization
- satellite monitoring
- electric mapping and sounding
- self-potential technique
- seismic refraction and reflection
- GPR
- resistivity sounding
- well logging



Mapping geophysics to SDG 4 — Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all

Collaboration and expansion opportunities

- Facilitate the transfer of geoscience research and sustainable applications between industrialized and developing countries.
- Hire local geophysicists and students to be part of geophysical operations.
- Support community-driven projects with education and training for workforce and students (apprenticeships, scholarships).
- Promote geophysics in education:
 - Highlight that geophysics is a science with a broad range of applications and career paths.
 - Incorporate sustainable development and environmental stewardship into geoscience curricula.
 - Increase exposure of geosciences to primary- and secondary-school students.
 - Strengthen support for syllabi in graduate-school geophysics programs. Foster establishment and expansion of professional-development programs in geophysics.
 - Encourage participation of students in geophysical aspects of community-driven projects.
 - Support local professional geoscience student and professional chapters and sections.
- Focus on local resources and hazards to create customized geophysics educational programs.
- Ensure the availability of educational materials, sharable databases, and software in different languages and systems.
- Make information, databases, and publications more accessible, or free of charge, to society at large (e.g., Research4Life, FameLab).
- Engage industry operators in all sectors and academia in sharing geophysical knowledge and equipment for students and entrepreneurs.
- Consider establishing geophysical certification processes where feasible.
- Develop two-year degrees in geophysics to address local workforce needs.
- Collaborate with societies and geophysics institutions to ensure alignment and enhance geophysics-related local or regional government policies and legislation.



Mapping geophysics to SDG 5 — Achieve gender equality and empower all women and girls

Collaboration and expansion opportunities

- Better promote the image of the geophysics sector for women, highlighting the technology and digital aspects and giving relevance to female role models.
- Reduce unconscious gender biases in recruitment, progression, and promotion. Ensure there are no barriers to professional development of women. Incorporate flexible scheduling for child or elder care.
- Maximize awareness of the importance of gender balance in achieving profitability and success and promote the value of building gender-balanced pools of geophysicists in academia as well as industry.
- Incorporate best practices in gender diversity and inclusion in the geosciences.
 - In academia, boost the proportion of women in geoscience education programs. Raise the profile of geophysics and demonstrate the broad range of career opportunities in it.
 - In industry, reach gender equality in the intake of employees. Ensure the workplace is safe for women. Maximize exposure of female role models and mentors where possible, especially in oil and gas and the mining sector. Connect female geoscience professionals with undergraduates.
 - In professional societies, raise the profile of female geoscientists. Augment and promote the participation of female leaders in key roles. Disseminate best practices in gender diversity and inclusion across professional societies and to individual members.

6 CLEAN WATER AND SANITATION




Mapping geophysics to SDG 6 — Ensure availability and sustainable management of water and sanitation for all

- 1) Improve groundwater resource management by using geophysics tools for basin characterization, monitoring groundwater-recharge facilities, and assessing groundwater quality and groundwater surface-water interactions.
- 2) Monitor aquifer sustainability and support quantification of damage from overuse and impacts from climate change, such as droughts, inundation, sea-level rise, and agricultural impact on groundwater resources and quality. Monitor contaminants in the critical and vadose zones.
- 3) Use mapping and imaging to assess the effects of climate change on fresh/saltwater interface that impact drinking water and agriculture in coastal communities.
- 4) Follow best working practices regarding resource use and sanitation on land seismic projects.
- 5) Utilize seismic data to support more efficient and cleaner disposal of wastewater through proper identification and monitoring of wastewater well disposal sites.

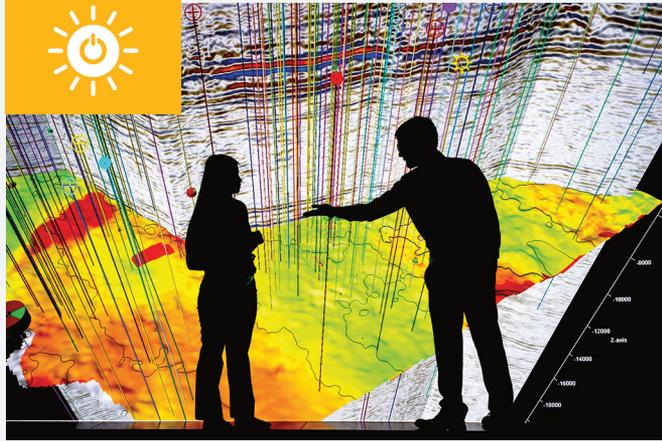
Collaboration and expansion opportunities

- Involve the community in assessing and monitoring water resources with geophysical techniques and share the geophysical data openly and with transparency.
- Follow and promote water-management legislation.
- Train local communities in effective water management.

Geophysical enablers

- seismic
- electromagnetic and electrical resistivity
- resistivity
- magnetics
- GPR
- nuclear magnetic resonance (NMR)
- remote sensing
- satellite monitoring
- groundwater modeling

7 AFFORDABLE AND CLEAN ENERGY

Mapping geophysics to SDG 7 — Ensure access to affordable, reliable, sustainable, and modern energy for all

- 1) Optimize hydrocarbon exploration and production through geophysical play and prospect evaluation. Geophysical techniques are pivotal to extending the lifecycle of hydrocarbons to enable access to energy for all until cleaner options are at scale.
- 2) Tackle emissions from hydrocarbons through CO₂ storage monitoring and methane detection and mapping.
- 3) Accelerate the clean energy transition through the characterization of deep and shallow geothermal systems, derisking for marine-resource exploration (wave, tidal, and wind), the storage of hydrogen, and environmentally and socially responsible mineral exploration to supply renewable technologies (wind turbines, electric vehicles, batteries, solar panels, etc.).
- 4) Ensure minimal impact of all geophysical operations on the surrounding environment.

Collaboration and expansion opportunities

- Communicate the crucial role played by geophysicists in all energy and decarbonization strategies to ensure energy security, equity, and environmental sustainability.
- Champion exemplary social and environmental responsibility during geophysical operations.

Geophysical enablers

- magnetics
- gravity
- seismic reflection and refraction
- AVO
- borehole seismic
- processing
- imaging
- reservoir characterization
- well logging
- inversion
- electromagnetic techniques
- machine learning and automation
- unmanned aerial vehicle (UAV) and satellite surveys

8 DECENT WORK AND ECONOMIC GROWTH




Mapping geophysics to SDG 8 — Promote sustained, inclusive, and sustainable economic growth, full and productive employment, and decent work for all

Collaboration and expansion opportunities

- Train and employ local workforce in geophysical techniques and operations. Assess skills gaps and map those to employment opportunities. Ensure knowledge and skills are transferable to subsequent project opportunities.
- Empower local talent to assume supervisory/managerial positions.
- Collaborate and engage with local academic institutions and geophysical companies to provide growth opportunities.
- Promote availability of geophysical industrial internships and apprenticeships.
- Increase access to geophysics-related resources (textbooks, journals, webinars, courses, and workshops).
- Make geophysical data more available to local companies and academic institutions.
- Review legislation and tax relief available to help enable local procurement (services, workforce, materials, and technology) and conduct local research.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE




Mapping geophysics to SDG 9 — Build resilient infrastructure, promote inclusive and sustainable industrialization, and foster innovation

- 1) Incorporate geophysical techniques and understanding of the subsurface to assist with the construction and monitoring of smart sustainable cities.
- 2) Maximize the use of geophysics for maintenance and monitoring of critical infrastructure (airports, hospitals, highways, dams, levees, etc.).
- 3) Apply industry geoscience technology and knowledge to address today's sustainability challenges such as water security, clean energy, decarbonization, and contamination.
- 4) Establish data and database sharing opportunities and processes to optimize knowledge sharing and collaboration.

Collaboration and expansion opportunities

- Enable collaboration schemes for technology transfer between industry and service companies, suppliers, academia, and local professional organizations.
- Engage local governments on the need for a thorough understanding of the subsurface to inform infrastructure policy.
- Test new ways to apply geophysical technology advances to a wide range of sectors.
- Promote legislation supporting application of geophysical techniques to risk analysis, earthquake-resistant infrastructure, and environmental protection.

Geophysical enablers

- seismic monitoring
- drones for geophysical mapping
- airborne electromagnetic surveys
- borehole analysis
- subsurface characterization
- GPR
- InSAR

10 REDUCED INEQUALITIES




Mapping geophysics to SDG 10 — Reduce inequality within and among countries

- 1) Address and mitigate impacts of climate change that disproportionately affect lower-income communities by using geophysical techniques to accelerate and support clean-energy transition, reduce emissions, safeguard access to water, and monitor sea-level rise and coastal erosion.
- 2) Educate local press, communities, and school systems on the benefits of geophysical studies for local development and hazard preparedness.
- 3) Incorporate geophysics in exploration and exploitation practices, assessing economic, environmental, and social impacts of activities on local, regional, and international communities.
- 4) Respect and preserve local indigenous culture related to use of land, communication, and traditions.
- 5) Ensure the integration of diversity in all its facets is achieved in all geophysical activities: age, ethnicity, culture, religion, nationality, socioeconomic stratum, language, even experience level or other characteristics, aiming to reduce inequalities within the discipline.

Collaboration and expansion opportunities

- Initiate communication and educational geophysical campaigns with local government and communities.
- Promote ethical and social roles of geoscientists through academic programs and professional training.
- Include social impact assessments in geophysical project planning.
- Adapt geophysical workflows to ensure preservation of local/indigenous traditions and use of resources.

Geophysical enablers

- UAV and satellite surveys
- data processing
- magnetic techniques
- magnetic, gravimetric, and seismic (refraction/reflection) techniques
- electromagnetic and electrical resistivity
- borehole seismic techniques
- reservoir characterization
- resistivity
- geophysical log and survey interpretation
- time-lapse seismic technology
- electromagnetic techniques
- machine learning and automation
- AVO
- GPR
- imaging
- inversion
- NMR
- remote sensing

11 SUSTAINABLE CITIES AND COMMUNITIES




Mapping geophysics to SDG 11 — Make cities and human settlements inclusive, safe, resilient, and sustainable

- 1) Contribute to the construction and enhancement of sustainable cities by advancing understanding of their subsurface geology, their geohazard risks (earthquakes, landslides, etc.), and the integrity of their infrastructure components such as bridges, highways, railways, airports, and underground tunnels. Help determine optimum clean-energy sources for these cities. Promote community engagement throughout project lifecycles.
- 2) Engage in transformation projects of current cities to uplift their sustainability.
- 3) Assist in locating, monitoring, and preserving land and underwater archeological sites and artifacts, cultural/city monuments, and indigenous cultural sites.

Collaboration and expansion opportunities

- Apply geophysics toward the protection and promotion of international geoharitage sites in alignment with the UNESCO Global Geoparks program, which safeguards the earth's geodiversity through conservation, education, and community engagement.
- Ensure geophysical studies and techniques are central to sustainable and resilient urbanization.

Geophysical enablers

- GPR
- ambient seismic techniques
- electrical techniques
- time-lapse studies
- surface-wave technologies
- satellite observations
- tomography
- echo sounding
- sonar



Mapping geophysics to SDG 12 — Ensure sustainable consumption and production patterns

- 1) Reduce hydrocarbon contamination and mining-related waste through geophysical detection and monitoring techniques. Employ remote data collection to avoid excessive drilling. Ensure responsible closure and rehabilitation of mines.
- 2) Map and monitor methane emissions to support the goals of the Paris Agreement greenhouse gas reduction targets.
- 3) Investigate and monitor landfill sites to assess cap-rock integrity and identify contamination plumes and waste concentrations.
- 4) Reduce water waste through operational efficiency informed by geophysical monitoring; treat and reuse water where possible (e.g., for irrigation); and ensure proper disposal.
- 5) Support use of cleanest natural resources available in the construction of sustainable and resilient cities.

Collaboration and expansion opportunities

- Design, deliver, and engage in campaigns to raise awareness of the potential of geophysics to monitor liquid and waste disposal on land and underground.
- Elevate the consciousness among geoscientists about responsible consumption and production, launching collaborative efforts and initiatives.
- Educate local communities in sustainable resource management.

Geophysical enablers

- ground-conductivity mapping
- resistivity tomography
- 3D modeling
- satellite remote sensing
- UAV imagery
- electromagnetic-induction surveying
- seismic reflection
- gravity



Mapping geophysics to SDG 13 — Take urgent action to combat climate change and its impacts

- 1) Position geophysics as central to decarbonization strategies, with emphasis on carbon capture, utilization, and storage and CO₂ storage-site characterization and monitoring.
- 2) Measure and monitor methane emissions from hydrocarbon and mining operations to inform reduction strategies in alignment with Paris Agreement targets.
- 3) Participate in exploration for renewable resources, including geothermal energy, wind, and hydrogen.
- 4) Support fuel switch from coal to natural gas to reduce greenhouse gas emissions and other air pollutants. Give priority to identify, study, and develop prospects with lower carbon footprints.
- 5) Promote energy efficiency and the use of clean energy during all geophysics-related operations.
- 6) Mitigate the impacts of climate change such as sea-level rise, glacier shrinkage, ice shelf collapse, flooding, droughts, coastal erosion leading to land instability, subsidence, and other geohazards by monitoring with geophysical techniques any changes that increase risk.
- 7) Measure and monitor ocean acidification coming from absorbed CO₂ emissions, which threatens global marine ecosystems and negatively impacts livelihoods and community development.
- 8) Actively involve local communities in climate action-focused geophysical operations.

Collaboration and expansion opportunities

- Implement safe and environmentally sensitive geophysical operations offshore and onshore, specifically in sensitive areas, such as fluvial, jungle, rainforest, glacial, and lacustrine environments.
- Engage in collaborative climate-action efforts among the geoscientific community at large.

Geophysical enablers

- inversion
- time-lapse analysis
- reservoir characterization
- UAV and satellite surveys
- seismic refraction and reflection
- borehole seismic
- automation and machine learning
- conductivity, temperature, depth (CTD) sensing
- AVO
- gravity
- magnetometry



Mapping geophysics to SDG 14 — Conserve and sustainably use the oceans, seas, and marine resources for sustainable development

- 1) Monitor sea-level rise, marine change, and coastal erosion.
- 2) Map the ocean floor to aid in the understanding of ocean circulation, weather systems, sea-level rise, tsunami wave propagation, sediment transport, benthic habitat distributions, and climate change to assist in policy decisions related to the sustainability of the oceans.
- 3) Use geophysics to understand and manage water quality and contamination from offshore operations, the shipping industry, pipeline leaks, and ocean acidification.
- 4) Ensure geophysical operations have minimal impact on marine habitats. Employ low-impact techniques, e.g., vibrators rather than explosives, compressed-air seismic sources rather than explosive charges at sea.
- 5) Map and monitor marine sanctuaries and preserves. Be active in promoting awareness about how geophysicists can support their sustainability.

Collaboration and expansion opportunities

- Identify, communicate, and raise awareness about geohazards such as hydrates and marine landslides to contribute to risk assessment for offshore operations.
- Participate in multiorganizational initiatives aimed at preserving life below water.
- Communicate to elementary, high-school, and university students the importance and impact of geophysics to map and monitor water quality and its relevance for sustainability.
- Ensure technical support pertinent to geophysics for policy decisions related to the sustainability of the oceans.

Geophysical enablers

- seismic reflection
- acoustic sensing
- GPR
- numerical modeling
- UAV imagery
- electromagnetic induction
- CTD sensing



Mapping geophysics to SDG 15 — Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss

- 1) Assist in precision farming with geophysical mapping and monitoring capabilities. Measure and monitor fertilizer, soil salinity, and waste nutrients in the subsurface for improved crop and harvest planning.
- 2) Monitor water quality, availability, and pollution for agricultural purposes and capacity. Manage water resources transparently and minimize land usage during geophysical operations.
- 3) Reduce the vulnerability of agricultural communities to the impacts of natural disasters (earthquakes, tsunamis) and climate-related events (flooding, landslides) by informing them about the risks and supporting their preparedness.
- 4) Establish boundaries of endangered areas, and monitor forest-fire occurrence and risk.
- 5) Conduct extensive environmental impact assessments during geophysical operations.
- 6) Support and conduct assessments of the impact of renewable energy technology using geophysical monitoring techniques when feasible.
- 7) Provide access to updated geophysical databases to academia and researchers to support monitoring of life on land. Review and share up-to-date data in accessible databases globally.

Collaboration and expansion opportunities

- Support and monitor biodiversity and habitat management through collaborative efforts with agricultural organizations and practitioners of other disciplines.
- Clearly and visibly communicate geophysicists' pivotal role in sustaining life on land to civil society, students, media, governments, and nongovernmental organizations (NGOs).

Geophysical enablers

- near-surface geophysics
- satellite monitoring
- data analytics
- drones
- seismic reflection and refraction

16 PEACE, JUSTICE AND STRONG INSTITUTIONS



Mapping geophysics to SDG 16 — Promote peaceful and inclusive societies for sustainable development, provide access to justice for all, and build effective, accountable, and inclusive institutions at all levels

Collaboration and expansion opportunities

- Attain a social license for natural-resource exploration operations (hydrocarbons, water, mining) by incorporating human-rights assessment, strategic environmental assessment, and climate proofing.
- Incorporate sustainability into geophysics best practices in industry and academia and within professional societies, ensuring dissemination at all levels.
- Integrate social governance into geophysics projects, ensuring transparent social engagement throughout project lifecycles.
- Communicate the importance of applied geophysics in society to the public, governments, the media, and other scientific communities.
- Utilize best practices in project management, including detection and action regarding legislation gaps and biases related to minorities and institution of antimonopolistic and anticorruption workflows globally.
- Include sustainable development in academic and professional training.
- Adhere to guidelines and best practices of societal engagement. Include community representation in geophysical operations.
- Raise awareness locally, nationally, and internationally about the benefits of geophysics to society. Actively contribute to debates on the role of geophysicists in advancing the UN SDGs.

17 PARTNERSHIPS FOR THE GOALS



Mapping geophysics to SDG 17 — Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development

Collaboration and expansion opportunities

- Create awareness and buy-in among local, national, and international governmental organizations on how geophysics can contribute to policy making.
- In line with UNESCO guidance, geoscientists (at all levels, in all sectors) should encourage and promote effective public, public–private, and civil-society partnerships.
- Advance collaboration, alignment, and partnership among geophysicists in government, academia, NGOs, industry, and professional societies, and form a consensus to advance the SDGs.
- Promote the inclusion of geophysics research, databases, and techniques in climate-action plans to positively contribute in policy and treaty negotiations.
- Engage in individual and collective active participation in professional societies, industry, academia, governmental, and multilateral organizations to cultivate awareness about sustainability. Examples include but are not limited to SEG, the American Association of Petroleum Geologists, the European Association of Geoscientists and Engineers, the American Geophysical Union, the American Geosciences Institute, the Society of Petroleum Engineers, Gaia, IPIECA, the International Union of Geological Sciences, UN SDGs, UNESCO, and universities.
- Strengthen coordination between these groups in advancing SDGs within geophysics.
- Communicate to civil society, students, media, governments, and NGOs geophysicists’ pivotal role in sustaining life on earth.
- Propel the mindset change needed to instill sustainable development into the consciousness of all geoscientists.

The Geophysical Sustainability Wheel

To summarize the mapping exercise of geophysics to the SDGs, an infographic was crafted that encapsulates the most relevant and meaningful findings into what we call the “Geophysical Sustainability Wheel” (Figure 4). The wheel design follows graphic schemes used by other organizations in their own mapping and is inspired as an adaptation of the SDG circular graphic developed by the UN for communication purposes. The wheel is considered to be a succinct, appealing, and engaging tool to attract the attention of all generations into learning more about the purpose intended — raising awareness about how all geophysicists actively contribute to the advancement of the SDGs. It is presented as a graphical summary of the mapping done, with the potential to become a central element in awareness and training campaigns involving sustainability in geophysics.

Findings and the way forward

Geophysics contributes to and has the long-term potential to advance all 17 SDGs. There is an urgent need to raise the awareness and importance of the SDGs and the applicability of geophysics to them among geophysical

practitioners as well as internal and external stakeholders. Professional societies related to geophysics have an important role to play in sharing this Geophysical Sustainability Atlas and its potential value with organizations, companies, and academic institutions. This atlas empowers geophysicists to identify their contributions at the individual, team, organization, and country level in pursuit of the UN SDGs. This will provide a sense of pride and belonging to all geophysicists.

For decades, most professionals in applied geophysics have focused their work on conventional oil and gas and mining exploration. Yet in recent years, increasing numbers have become engaged in CO₂ sequestration and energy and storage, enhanced oil recovery, near-surface investigations, underground water resource management, infrastructure integrity, and the sourcing of renewable energy — all progressively being driven by digitalization or digital transformation.

The geophysical language needs to expand beyond the profession’s traditional set of technical terms to accommodate the different semantics, skills, and especially the integrative and humanitarian vision and objectives of the SDGs, with the understanding that only with a wider scope



Figure 4. The Geophysical Sustainability Wheel — a diagram summarizing how each SDG may be supported and advanced through geophysics.

can we make relevant and significant contributions to the attainment of those goals.

A change of mindset is needed. The sustainability of the geophysics profession requires framing its current and usual activities to the SDGs to understand our own strengths, which are indeed many, but also our weaknesses. The exercise of having mapped geophysics' main activities into the SDGs enables the pursuit of long-term goals by individuals and organizations and empowers all of us to work with purpose and with sustainable consciousness.

The Geophysical Sustainability Atlas can inspire each geophysicist when they see the applicability of their expertise and skills within a global and strategic framework.

The applicability of the atlas will be feasible only with buy-in from geophysics stakeholders, which may be clustered in two main groups:

- 1) **External stakeholders:** Communities affected by geophysical operations, legislators, unions, organizations involved in preservation of the environment, organizations pursuing betterment of society, investors and financial institutions, and regulators.
- 2) **Internal stakeholders:** Leadership, managers, employees (staff), business developers, operational personnel, and researchers in companies and institutions that practice geophysics; faculty, administrators, and students in academic institution, and professional organizations related to geophysics.

Many initiatives to support SDGs call for organizational action, but others could be advanced at the individual level by each geophysicist in her or his area of influence. Some questions that may exemplify how to trigger reflections and actions in sustainability include:

- Are there seismicity standards and is there legislation pertinent to infrastructure-building parameters for human, industrial, and animal settlement in my country/region/organizations? (SDGs 3 and 9)
- Are electromagnetic surveys required in my city/area/community/country/region to preserve underground aquifers and water courses on the ground (seasonal rivers, streams, and seasonal flooding plains)? Is there legislation about this topic? (SDGs 6, 11, 12, and 15)
- Are primary and secondary schools and community colleges where I live prepared to teach about earthquake/seismicity levels, volcanoes, landslides, and other hazards in their localities? Have I proposed to deliver an awareness session about the geohazard specifics of my city/region/country to the schools or universities in my community? (SDGs 4, 10, and 11)

It becomes clear then that each one of us may play a role in advancing SDGs using geophysics. We particularly encourage geoscience professional societies to play an active role in advancing an understanding of the 17 SDGs to foster collaboration loops toward achieving them.

Conclusions

The results of mapping geophysics to the SDGs provide a pathway for geophysicists to act as pivotal workers in pursuit of society's sustainability goals, helping them examine their interests, expertise, and talents in a wider and noble context, which is extremely relevant for the sustainability of the profession.

We encourage other authors and researchers to further our work and identify specific additional ways geophysicists can work toward achievement of the SDGs. New pathways toward SDG achievement through geophysics practice will become apparent over time, so the Geophysical Sustainability Atlas must evolve.

- The Geophysical Sustainability Atlas outlines a first approach to consider what geophysics means to the pursuit of the 17 SDGs at global scale.
- We included all sectors of geophysics in the design of the atlas with the aim of triggering a sense of pride and belonging across the profession and raising awareness about the full spectrum of geophysical activities that can and do relate to the SDGs.
- The Geophysical Sustainability Atlas would benefit from an awareness campaign to maximize collective outreach into the profession, including each of its major sectors — oil and gas, unconventional, near-surface applications, academia, and mining, among others.
- There is a clear need to improve the skills, knowledge, and willingness of geophysicists and geophysical organizations to engage in assessments of their own economic, social, and environmental impacts and to optimize their participation and collaborative efforts toward achievement of the SDGs.
- Mapping geophysics to the 17 SDGs in collaboration with the focus groups revealed many opportunities to further develop the Geophysical Sustainability Atlas and strengthen it through buy-in of all stakeholders.

Reflections

Crafting this article put us in contact with remarkable global initiatives fully grounded in geophysics. We would like to highlight Geoscientists *Without Borders*, a humanitarian initiative of SEG, and the Ghost Net and Marine Debris Removal Initiative, an initiative of IAGC. These are just two wonderful examples of how geophysicists already contribute in significant ways to social, economic, and environmental aspects of sustainability.

This project was a result of a collaboration by virtual means from Kuwait, Ireland, and the United States during the COVID-19 pandemic. The “new normal” triggered in us unavoidable reflections on what matters and what we value the most. We value sustainability. We offer this work to all our peers in geophysics in the firm belief that it supports a positive and integrated path toward pursuing the 17 SDGs for 2030. **III**

Acknowledgments

This article benefitted from the substantial personal efforts, enthusiasm, and especially the expertise of key individuals who

were instrumental in identifying how to map the complex and exciting world of geophysics to the SDGs. We would like to express our utmost appreciation to the following individuals who generously contributed their time and expertise to this work.

Key collaborators and supporters included Ted Bakamjian, Herminio Passalacqua, Wafik Beydoun, Estella Atekwana, Maurice Nessim, Brian Sullivan, Robert Cox, and Johana Dunlop.

Focus Group 1 consisted of Susan Webb, Jenny Thompson, Allen Bertagne, Ted Bakamjian, Linda Ford, Mike Loudin, Herminio Passalacqua, Richard (Rick) Miller, Pallavi Bharadwaj, Manika Prasad, and Laurie Whitesell.

Focus Group 2 consisted of Adriana Citlali Ramirez, Nancy House, Estella Atekwana, Linda Ford, John Koehr, and Ulrike Schopp.

Focus Group 3 consisted of Gustavo Carstens, Wafik Beydoun, Ulrike Schopp, Mike Loudin, and Johana Dunlop.

Expert collaborators and stakeholders included Nikki Martin, Criss Rennie, Jameson White, Gail Adams, Dustin Van Liew, Asmita Mahanta, and Ashley Grant.

Corresponding author: mariangelacapello@gmail.com

References

IPIECA, UNDP, and IFC, 2017, Mapping the oil and gas industry to the sustainable development goals: An atlas, https://www.ipieca.org/media/3093/mapping_og_to_sdg_atlas_lr_2017.pdf, accessed 10 December 2020.

United Nations, n.d., Sustainable development goals, <https://www.un.org/sustainabledevelopment/sustainable-development-goals/>, accessed 10 December 2020.

Recommended resources

- Geology for Global Development, <https://www.gfgd.org/>
- Geoscience Communication, <https://www.geoscience-communication.net/>
- Geoscience and society, <http://geologize.org/>

- Geoscientists Without Borders, <https://seg.org/about-seg/geoscientists-without-borders>
- Global Carbon Capture & Storage Institute, <https://www.globalccsinstitute.com/>
- IAGC, <https://iagc.org/>
- IAGC Ghost Net Initiative, <https://iagc.org/policy-issues/ghost-net-initiative/>
- International Association for Promoting Geoethics, <https://www.geoethics.org/>
- International Union of Geological Sciences, <https://www.iugs.org/>
- IPIECA, <https://www.ipieca.org/>
- Oil and Gas Climate Initiative, <https://oilandgasclimateinitiative.com/>
- Seabed 2030, https://www.gebco.net/about_us/seabed2030_project/
- SPE Gaia Sustainability Program, <https://www.spe.org/en/gaia/>
- Sustainable Earth Institute, <https://www.plymouth.ac.uk/research/institutes/sustainable-earth>
- UNESCO Earth Science, <http://www.unesco.org/new/en/natural-sciences/environment/earth-sciences>
- United Nations Office for Disaster Risk Reduction, <https://www.undrr.org/>
- United Nations Sustainable Development Goals, <https://sdgs.un.org/goals>

Editor's note: The Geophysical Sustainability Wheel was adapted from the United Nations Sustainable Development Goals wheel and implies no UN endorsement.



© The Authors. Published by the Society of Exploration Geophysicists. All article content, except where otherwise noted (including republished material), is licensed under a Creative Commons Attribution 4.0 Unported License (CC BY). See <http://creativecommons.org/licenses/by/4.0/>. Distribution or reproduction of this work in whole or in part commercially or noncommercially requires full attribution of the original publication, including its digital object identifier (DOI).