A Path to the Reduction of Marine Seismic CO_2 Emissions

PGS is committed to advancing several of the United Nations Sustainable Development Goals (SDGs), including SDG 13: Take urgent action to combat climate change and its impacts. Management are maintaining the target to reduce relative CO_2 emissions (t CO_2 per CMP km) by 50% compared to 2011 within 2030, and leverage digitalization to identify emission reduction opportunities and meet future greenhouse gas (GHG) monitoring and reporting obligations.

As described below, DataOps optimization of vessel and survey management has been applied to the four Titan-class Ramform seismic vessels since 2020 and allows tracking of fuel consumption and CO_2 emissions per CMP km. Drag reduction initiatives and novel survey designs to reduce CO_2 emissions per CMP km and improve survey efficiency are also being considered.

Sustainability Goals and Risk Reduction

The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. The 17 SDGs build on decades of work by countries and the UN, including the UN Department of Economic and Social Affairs that began in June 1992, and each SDG each contains several targets and associated indicators.

PGS is corresponding committed to realizing several of the UN SDGs (two relevant SDGs being highlighted in **Figure 1**), and promote good management of sustainability and Environmental, Social and Governance (ESG) opportunities and risks as being essential to business success. It motivates employees, investors, customers, and other stakeholders on whom businesses rely on to operate successfully and safely. Comprehensive details are in the Annual Report and Sustainability Report for 2021. PGS has sustainability targets relevant to UN SDGs 4, 7, 9, 13 and 14. **This newsletter addresses PGS initiatives and technologies relevant to UN SDG 13: Take urgent action to combat climate change and its impacts**.

9 INDUSTRY, INNOVATION AND INFRASTRUCTURE — Upgrade seismic operations through digitalization and innovation.	Embedded digitalization as a core enabler of our strategic objectives.	Use digitalization to enable seismic exploration with a reduced GHG footprint.
13 CLIMATE ACTION — Reduce relative CO_2 emissions (t CO_2 per CMP km) by 50% compared to 2011 within 2030	Revised our GHG inventory to meet future reporting requirements. Implemented real-time fuel consumption and energy efficiency dashboards for Titan-class vessels.	Evaluate feasibility of alternative fuels for our fleet. Develop real-time monitoring of GHG emissions to enable detailed analysis of reduction alternatives. Report our emissions and progress towards target on a quarterly basis.

Figure 1: PGS attention to United Nations Sustainable Development Goals (SDGs) in 2021 and 2022 that are relevant to the pursuit of reduced GHG emissions and the application of digitalization.

Sustainability Risks and GHG Emissions

The direct emissions from our fleet of seismic- and support vessels represent more than 95% of the PGS total emissions of greenhouse gases (GHG). During 2021, PGS used the framework recommended by the Task Force on Climate Related Disclosures (TCFD) and performed a high-level assessment of the transition- and physical risks related to climate change. The assessment is based on reporting to the Climate Disclosure Project (CDP) and includes areas of high-level management focus related to the identified risks and opportunities. **Table 1** is taken from the Sustainability Report for 2021 and includes those elements relevant to **GHG emissions**.

Risks	Opportunities	Management Focus
TRANSITION RISKS		
POLICY AND LEGAL		
• Increased pricing of GHG emissions • Enhanced reporting obligations • Mandates on and regulation of existing products and services • Exposure to litigation	• Use of supportive policy incentives • Participation in carbon markets • Use of lower-emission sources of energy	• Monitor policy and regulatory developments • Leverage digitalization to meet future reporting obligations. • Robust governance and compliance framework in place. • Target to reduce relative CO2 emissions by 50% in 2030.
TECHNOLOGY		
• Substitution of existing products and services with lower emissions options • Unsuccessful investment in new technologies • Costs to transition to lower emissions technology	• Development and/or expansion of low emission goods and services • Development of new products or services through R&D and innovation • Use of new technologies	• Investment in technology R&D and digitalization. • Evaluation of emission reduction technologies. • Evaluation of alternative fuels.

Table 1: Risks and opportunities associated with climate change and the energy transition. Taken from the Sustainability Report by PGS for 2021.

PGS Target for Reduced CO_2 Emissions

In 2021, PGS managed to maintain its path towards a 50% reduction in equivalent CO_2 emissions per data unit, referenced to the emissions in 2011 (**Figure 2**). The phrase "equivalent CO_2 emissions" refers to how much a gas contributes to global warming, relative to carbon dioxide. While progress shown in **Figure 2** can be contributed to the actions taken so far, it is also highly dependent on the market situation and dynamics and the resulting activity level and fleet allocation.

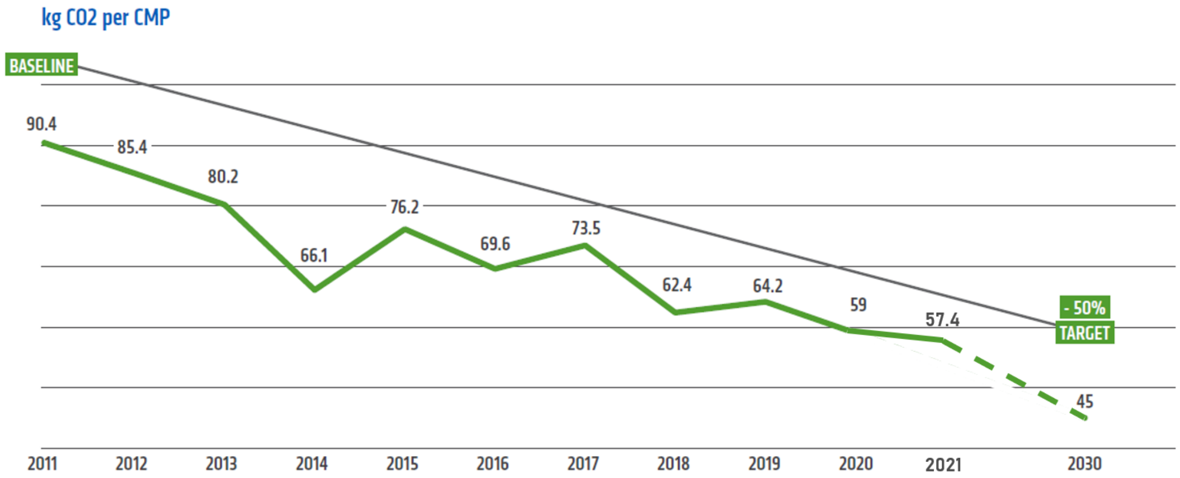


Figure 2: PGS GHG emissions per CMP km since the reference baseline in 2011. Our target is 50% reduction within 2030. Further details are in the Annual Report and Sustainability Report by PGS for 2021.

Looking forward to further reductions in equivalent CO_2 emissions, a 'sweet spot' exists between efficiently acquiring marine seismic surveys to reduce cost and operating to minimize equivalent CO_2 emissions (see also below).

Continuous PGS investments over many decades in modern vessels and seismic technology have resulted in less downtime during production, less gaps in the seismic data coverage that needs to be re-acquired and less standby for weather and currents. A shorter survey duration also minimizes the acoustic survey footprint. Now, a long-standing focus upon novel survey designs and configurations that can improve efficiency is being adapted to also reduce equivalent CO_2 emissions.

A key to further reductions will be smarter survey management through the application of artificial intelligence (AI) and data science analytics. A clear ambition exists to achieve overall faster vessel speeds, allow the vessels to safely operate in a manner that accommodates highly dynamic ocean currents and prevailing conditions, maximize the signal quality of the extremely weak acoustic information being recorded, and simultaneous monitor and minimize fuel consumption. No trivial feat!

Greenhouse Gas (GHG) Emissions and Fuel Consumption

New regulatory guidelines on how GHG emissions are defined and measured are relevant to the targets discussed here and will influence survey design principles being developed to efficiently acquire marine seismic data with minimum emissions. The IMO guidelines are established, and the FuelEU Maritime proposal below may impose the precedence for even stricter obligations on emissions reductions when approved.

Maritime Fuel Consumption and GHG Emissions Reporting: IMO

PGS has historically reported its GHG emissions according to the standards of the International Maritime Organization (IMO), an agency of the United Nations formed to promote maritime safety.

In 1973, IMO adopted the International Convention for the Prevention of Pollution from Ships, now known universally as MARPOL. Bunker fuels used for the maritime industry are analyzed according to ISO 8217:2017, Annex VI of the MARPOL Agreement and other specifications. In 2011, IMO adopted mandatory technical and operational energy efficiency measures which are expected to significantly reduce the amount of CO_2 emissions from international shipping. Notably, the Energy Efficiency Design Index (EEDI) was made mandatory for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships at MEPC 62 (July 2011). MEPC 70 (October 2016) adopted mandatory MARPOL Annex VI requirements for ships to record and report their fuel oil consumption, and PGS follows these standards when reporting their GHG inventory.

Adopting IMO Emissions Targets to 3D Marine Seismic Surveys

Although the IMO CO_2 reduction ambition refers to units of CO_2 per tonne mile, the unique execution of seismic surveys requires a more appropriate target. As schematically illustrated in **Figure 3** below, many parallel 'sail lines' are acquired in a manner that seeks to yield continuous and contiguous 'subline' coverage, and although transient in nature, a 3D marine seismic survey involves a vessel(s) operating within a specific geographical region over a prolonged time interval.

The equivalent CO_2 reduction target correspondingly adopted by PGS defines "tonnes of CO_2 per CMP km" (where each 1 km subline interval represents 1 km of CMP acquisition). With reference to **Figure 3**, a common midpoint (CMP) is a discrete location specified in surface coordinates that is exactly halfway between the surface coordinates of an arbitrary source location and receiver location. An assumption is made that each CMP occurs directly above all the subsurface illumination points for all horizontally layered geological strata that correspond to that associated source and receiver at an instantaneous moment in time. As each streamer, typically about 8 km in length, contains a receiver distributed every 12.5 m along the streamer, there will be a 'subline' of CMP locations corresponding to a source location at an instantaneous moment in time and all the receivers for each streamer (assuming uniform streamer geometry as shown). As the vessel moves along each sail line all the CMP locations along each subline are continuously re-mapped in an overlapping manner. Survey planning considerations relevant to reduced equivalent CO_2 emissions are discussed in more detail below.

Maritime Fuel Consumption and GHG Emissions Reporting: FuelEU Maritime

In September 2020, the European Commission (EC) adopted a proposal to cut greenhouse gas (GHG) emissions by at least 55% by 2030 and put the European Union (EU) on a path to becoming climate neutral by 2050. A 90% reduction in transport emissions is targeted by 2050 to achieve climate neutrality. All transport modes, including maritime transport, must contribute to the reduction efforts. Correspondingly, in July 2021, the European Commission released several policy proposals in its "Fit for 55" package, aimed at achieving the EU's goal, and including the following:

- Emissions trading system (ETS): EU allowances must be purchased for CO_2 emissions indexed to each ton of fuel used. Begins in 2023 (20% of verified CO_2 emissions) and ramped up to 2026 (100% of verified CO_2 emissions)
- Emissions taxation directive (ETD): a tax indexed to each ton of marine fuel used. Also begins in 2023
- Carbon intensity index: standardized monitoring of equivalent CO_2 emissions from each ton of marine fuel used, and the basis of the discussion below

The proposed EC regulation referred to hereafter as FuelEU Maritime, aims to reduce average carbon intensity (CO_2 per tonne-mile) by at least 40% by 2030 and by 70% in 2050, as well as to cut total emissions by at least 50% by 2050, compared to 2008. FuelEU Maritime GHG intensity reduction requirements for 2025 to 2050 are assessed on a well-to-wake basis, considering the impacts of energy production, transport, distribution and use on-board.

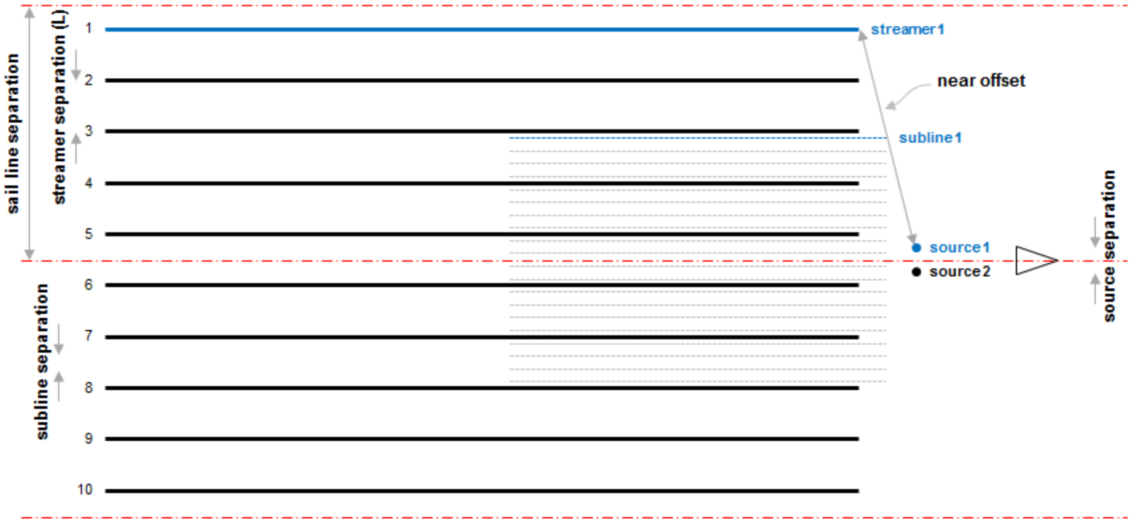


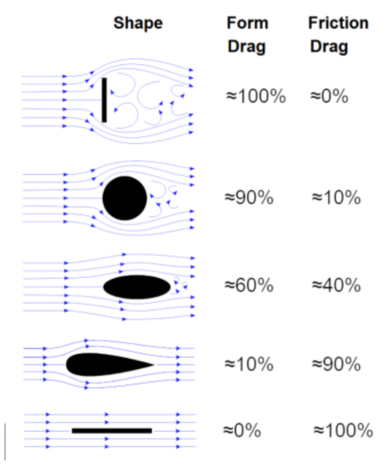
Figure 3. Schematic dual-source multi-streamer towing configuration. For uniform source and streamer geometry, there is a predictable linear relationship between the streamer spread geometry versus the nominal sail line separation, and between the source and streamer spread geometry versus the number of sublines and their separation. Each 'subline' corresponds to a line of common midpoints (CMPs) that correspond to a unique streamer and source identity. The 'near offset' for each subline is the shortest distance between the associated source and streamer locations.

Survey Design Parameters for Reporting and Reducing GHG Emissions

Increased Vessel Speed Increases Drag and GHG Emissions

All the systems on PGS vessels are electric: the thrusters (engines) connected to propellors that move the vessel, the air compressors that produce the air periodically released into the water to precisely generate acoustic pressure waves downwards into the earth, and all 'hotel' (i.e., personnel) and auxiliary consumers (generally an 85/10/5 split). The electricity is produced by several generators that use various fuel types, so the amount of fuel being consumed at any moment time is mainly related to the effort required by the engines. Correspondingly, the overwhelming contributor to engine effort, vessel fuel consumption and therefore GHG emissions is hydrodynamic drag associated with the vessel and all the trailing equipment.

Figure 4. Schematic illustration of fluid flow around various body shapes and the relative contribution of form drag, and friction drag to the overall drag forces.



The drag force on any object is proportional to the density of the fluid and proportional to the square of the relative flow speed between the object and the fluid. When this force in-line with the approaching fluid motion, it is composed of frictional drag (viscous drag) and form drag (pressure drag): refer to **Figure 4**. When the drag is dominated by a frictional component, such as affects a seismic streamer being towed behind a vessel, the body is called a streamlined body. In the case of dominant form drag, such as affects 'spreader' ropes between streamers in a spread or related to barnacle growth on underwater surfaces, the body is called a blunt or bluff body. Thus, the shape of the body and the angle of attack determine the type of drag. PGS invests considerable R&D effort into barnacle-mitigation solutions, the deployment of hydrodynamic fairings wherever form drag is expected, and the development of lower-drag seismic array configurations.

A minimum vessel speed is necessary to maintain control of the trailing equipment. As vessel speed increases, surveys are acquired more efficiently in terms of square kilometers of acquisition per day, but as drag affecting the vessel and all trailing equipment increases, so does tensions and associated mechanical noise modes throughout the streamers, and fuel consumption and GHG emissions increase due to higher engine loads.

As discussed below, near-real time capture of operational data illustrates that engine load, vessel speed and fuel consumption are not linearly related.

<u>Sail Line Geometry and Subline (CMP) Geometry</u>

A single vessel towing an array of streamers and sources will complete a survey as several 'sail lines', with an ambition of recording continuous and contiguous CMP (common midpoint) coverage. **Figure 3** shows a nominal vessel towing 10 streamers and two sources, with the lateral source separation equal to (0.5 x nominal streamer separation). For 100 m streamer separation the nominal source separation in this case is 50 m.

The CMP lines, referred to as 'sublines' are shown as feint dashed lines. Modern survey designs increasingly tow more than two sources (as many as six and referred to as 'multi-source' towing), often with some of the sources laterally separated by a distance larger than the nominal streamer separation (referred to as 'wide-tow multi-source towing") and may deploy the sources behind the front of the streamers rather than in front of the streamers as shown.

The nominal sail line separation that is equal to (0.5 x number of streamers x nominal streamer separation), determines how many sail lines are required to complete the survey, and therefore, how many days of vessel activity are required to complete the survey. For 100 m streamer separation the nominal sail line separation in this case is 500 m: the total survey area would be acquired as parallel sail lines with a nominal separation of 500 m. It follows that sail line separation is increased (shorter survey duration) by increasing the number of streamers and/or the nominal streamer separation.

The maximum 'near offset' shown below is particularly relevant for the seismic imaging of shallow geologic targets: if the near offset is too large the imaging of shallow geology will be compromised wherever the subline coverage from each sail line is adjacent to the adjacent subline coverage from other sail lines (the 'crossline acquisition footprint'). The maximum near offset can be reduced by increasing the lateral (i.e., crossline) separation between sources (wide-tow sources). Therefore, survey efficiency in areas where shallow geologic targets exist may benefit from the use of wide-tow sources: a larger streamer spread may be permissible than if the sources were all towed in the center of the streamer spread.

The spatial width of the subline coverage for each sail line is equivalent to the nominal sail line separation. The number of sublines per sail line is equal to (number of sources x number of streamers), and the subline separation is equal to (0.5 x streamer separation / number of sources). For 10 streamers with 100 m streamer separation and dual-source shooting there will be 20 sublines per sail line with nominal subline separation of 25 m.

A few fundamental survey design parameters are noteworthy:

- A larger number of sources deployed (multi-source towing) will increase the number of sublines per sail line in a <u>linear</u> manner
- <u>Towing a larger number of sources may</u> <u>reduce equivalent CO_2 emissions per CMP km</u> as a larger number of CMP km is acquired per sail line km
- Similarly, <u>towing more streamers for a given sail line separation</u> (i.e., with smaller associated streamer separation) may also increase the number of sublines acquired per sail line in a <u>linear</u> manner and therefore <u>reduce equivalent CO_2 emissions per CMP km</u>.

Denser subline acquisition will also improve seismic image resolution and quality as greater resolution of the recorded seismic wavefield can be preserved throughout the imaging workflow with a higher signal-to-noise ratio.

Larger numbers of sources will typically improve the 3D spatial sampling of the emitted source wavefield, and denser streamer spreads will improve the 3D spatial sampling of the receiver wavefield. Seismic images will have better vertical resolution (extended temporal frequencies) and fault planes and steep geological features will be better resolved (extended spatial wavenumber content).

Survey Design to Reduce GHG Emissions

The previous sections illustrate that higher subline density (i.e., more streamers and/or sources for a reference sail line separation) may decrease the equivalent CO_2 emissions per CMP km, assuming that the equivalent CO_2 emissions per sail line km are the same when towing more streamers and/or sources.

In practice, there are competing factors that must also be modelled when designing the ‘optimum’ source and streamer configurations to reduce emissions:

- The larger surface area of additional streamers being towed will increase drag and associated fuel consumption somewhat
- The use of large streamer spreads to maximize sail line separation and/or higher vessel speeds to acquire each sail line more quickly will also increase drag and associated fuel consumption
- Faster vessel speed will increase fuel consumption and increase mechanical noise within the streamers due to larger drag-induced flow turbulence and streamer tensions
- Vessel speed is typically constrained by a necessity to trigger the air guns on a uniform ‘shot grid’ and allow some minimum recording time between consecutive shots

Collectively, there is a complex interplay between survey parameters designed to optimize efficiency and data quality and how the dynamic forces experienced during a survey will affect fuel consumption and associated emissions.

The following section introduces some digital transformation initiatives that PGS are developing to accommodate the complexities of modern surveys and better manage their outcome.

The PGS Digital Factory

PGS began a digital transformation journey in 2019 by identifying three key projects for attention: 1. Build an inhouse digital factory to solve business problems and deliver tangible value back to PGS, 2. Develop a cloud enabled seismic imaging platform (PGS Eos), and 3. Provide the next generation subsurface data delivery/access system (PGS Solis). Partnerships were established with Google and Cognite, and PGS was reorganized to embrace the digital transformation ambitions. Using a mantra of “Start small and iterate”, all digitalization projects are run in an Agile manner with clear focus upon producing value at each step. In 2020 PGS first implemented real-time vessel speed management, fuel consumption and energy efficiency dashboards for Titan-class Ramform vessels and refined these tools in 2021. In 2022 PGS will evaluate the feasibility of alternative fuels for the fleet, as well as evaluate novel survey designs to reduce emissions.

The two solutions discussed below, Optimal Vessel Speed and Energy Efficiency, are now fully embedded into everyday PGS processes. Cognite Data Fusion™ (CDF) is the DataOps platform used to integrate data from many diverse sources available on the Titan-class Ramform vessels, contextualize the data and provide tools to enable both visualization and data science pursuits such as machine learning (ML). The PGS Digital Factory has many time series and events in CDF connected to a hierarchy of assets, and other data resources within CDF such as geospatial data are also utilized.

The vessel speed dashboard can provide real-time and retrospective insights. Relevant survey factors such as significant wave height, water speed at different points in the seismic array, vessel water bottom speed, tensions at different points in the seismic array, signal and noise attributes of the recorded seismic data, navigation data, and other factors are used to recommend the safest maximum vessel speed. ML algorithms are improving and validating suggestions from both historical and live data sources. Several vessel speed dashboards are available using web, PowerBI and Grafana tools:

- Real-time vessel speed data
- Retrospective vessel speed for reference time intervals (e.g., 48 hours)
- Optimal vessel speed using historical and live data
- Statistical breakdown of all factors contributing to the recommended vessel speed

Several energy consumption dashboards are also available:

- Real-time vessel fuel consumption and generator power performance
- Statistics for all generators

Next Steps: GHG Emissions Management

From a future planning perspective, these tools will be adapted to help reduce GHG emissions. Optimized utilization of the fleet usage will continue to be a priority, with minimum vessel activity assigned to non-seismic production. Inefficiencies in how a vessel operates during seismic acquisition will be investigated and used to reduce emissions whilst survey efficiency is being maintained. A tool to predict the fuel required for future projects would add confidence to budgetary forecasting and would enable the prediction of the “equivalent CO_2 budget” for a survey. Annual fuel consumption and emissions reporting such as that required by the IMO Data Collection System for fuel oil consumption (IMO DCS) will become automated and more accurate.

Figure 5 is an example of part of a vessel speed dashboard over a four-day interval. The superimposed profiles in the lower panel show the non-linear relationships between vessel speed over the seafloor, vessel speed through the water and fuel consumption. The various upper panels present a subset of contributing factors to the recommended vessel speed. The relative contribution of each contributing parameter to the predicted vessel speed will vary according to local survey conditions, the source and streamer spread being towed, and the subsurface properties. In this example, the main limiting factor on vessel speed was the requirement to maintain a specific time interval between consecutive shots. Vessel speed can accordingly be modified in a semi-automated manner that can optimize survey efficiency, relative CO_2 emissions, and data quality being recorded.

Figure 5: Part of a vessel speed dashboard that shows contributing data over a four-day interval.

Summary

An ambition of PGS is to promote the UN Sustainable Development Goals (SDGs) through concrete actions on goals that are relevant for our company activities and global presence. One of these goals is to reduce relative CO_2 emissions (t CO_2 per CMP km) by 50% compared to 2011 within 2030. As discussed, regulatory guidelines such as MARPOL Annex VI (IMO) and FuelEU Maritime (proposed by the EC) are used for the description and reporting of relative CO_2 (and GHG) emissions and provide incentives to adopt low-carbon fuels. The practical path to lower CO_2 emissions will expectably come from a combination of better survey design and execution, optimized fleet utilization, and drag reduction initiatives.

Seismic vessel operations are highly dynamic in nature so there are merits in having near-real time access to many contextualized data sources for vessel management. Dashboards within the PGS Digital Factory are correspondingly becoming a convenient platform to quickly audit many performance metrics. Not shown here is the value of building multi-year databases of attributes that will contribute towards the targeted reduction of relative CO_2 emissions on an annual basis. As work progresses, PGS will develop systems to monitor, analyze and optimize other elements of their global operations. An ambition for enhanced pre-survey planning is the development of tools to translate modelled dynamic loads and drag of a specific acquisition configuration into modelled fuel consumption versus vessel speed. It is anticipated that eventually the “equivalent CO_2 budget” can be predicted for a survey as a function of different key acquisition parameters.

Further Reading

- PGS and Sustainability (on-demand webinar)

- PGS Sustainability Report 2021 (PDF download)

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