MARITIME TECHNOLOGIES FORUM

LEADING THE MARITIME WORLD FORWARD

REVISED FRAMEWORK FOR ASSESSING DECARBONIZATION TECHNOLOGIES AND ALTERNATIVE ENERGY CARRIERS

Executive Summary

The MTF Framework for Assessing Decarbonization Technologies and Alternative Energy Carriers is a holistic framework to assess technologies and energy carriers for acceptance into the maritime environment.

The Framework is intended for broad use among maritime industry stakeholders, including ship owners, charterers, shipyards, equipment suppliers, flag states, classification societies, intergovernmental organizations and sustainability certification bodies.

The evaluation according to the Framework is a collaborative exercise that assesses the feasibility of proposed alternative fuels expected to drive the decarbonization of the maritime industry. The framework criteria work as a checklist, ensuring a systematic and standardized evaluation of technologies and energy carriers.

During the application of the Framework as reported in "Fuels evaluation through the MTF Framework for assessing decarbonization technologies and alternative energy carriers" in November 2022, MTF identified several improvement potentials. This report presents a revised Framework, improving the evaluation process, criteria and presentation of the evaluation. The revision is supported by a literature review of other frameworks and assessments. The revised Framework has been further tested by validating that the list of criteria captures known issues.

Introduction

The MTF Framework for Assessing Decarbonization Technologies and Alternative Energy Carriers is a holistic framework to assess technologies and energy carriers for acceptance into the maritime environment and long term use. While greenhouse gas emissions reduction is the ,main reason new technologies and fuels need to be evaluated, we need to also ensure we consider the impact of other social, economic and environmental factors when finding and applying solutions.[1]

The purpose of the framework is to:

- Provide a common view as to what criteria are important when assessing decarbonization technologies and alternative energy carriers
- Facilitate understanding and communication on assessed technologies and energy carriers
- As a result of the assessments, identify gaps where further regulations and standards are needed to remove barriers

The framework should, in general, be applicable for all decarbonization technologies and alternative low- and zero-carbon energy carriers.

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Disclaimer

The results here are a collaborative effort between all of the MTF members. Each organization within MTF may have an independent opinion different from the results presented in this report. This report does not preclude MTF members from having their own independent opinion or conclusion.

[1] Framework for assessing decarbonization technologies and alternative energy carriers, Maritime Technologies Forum (MTF). Available at https://www.maritimetechnologiesforum.com/documents/MTF-concept-paper.pdf

Review of Other Frameworks

In revising the MTF framework, a review of related frameworks within the marine industry has been undertaken. This is to test that (1) the MTF framework is addressing the relevant aspects associated with decarbonization and (2) to identify any gaps in published material that can be addressed by the MTF Framework. Each framework, or assessment, reviewed as part of this task is briefly discussed and then summarized in Table 2.

MEPC.376(80) provides the 'Guidelines on life cycle GHG intensity of marine fuels (LCA Guidelines)' and the first version of IMO's method to assess the well-to-wake GHG emissions and sustainability of marine fuels. An initial list of 101 fuel pathways is also included.[2]

The Nordic Roadmap project has provided a life cycle assessment of potential zero-carbon fuels in the Nordic context, addressing well-to-wake GHG emissions as well as other environmental impacts.[3]

The Sustainable Shipping Initiative has outlined sustainability issues, principles and criteria developed according to different feedstocks and primary energy sources for zero and low carbon marine fuels.[4]

Ricardo and DNV's Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels[5] assesses the feasibility of achieving various decarbonization ambitions, and provides among other things, an assessment of technology and commercial readiness and costs of various technologies and fuels, as well as a review of well-to-wake emissions of candidate fuels.

Lloyd's Register developed the zero-carbon fuel monitor[6], with the most recent edition showing an average increase in readiness across all fuels and supply chain stages from three perspectives: technology (TRL), investment (IRL) and community (CRL). Three main categories of fuel have been assessed to date including re-electrofuels, natural gas with carbon capture and sustainable biomass-derived fuels.

[2] MEPC.376(80) 'Guidelines on life cycle GHG intensity of marine fuels (LCA Guidelines), 7 July 2023.
Available at https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2014.pdf

[3] Life Cycle Assessment of Marine Fuels in the Nordic Region – Task 1C, Nordic Roadmap Publication No.1-C/1/2023.
Available at https://futurefuelsnordic.com/life-cycle-assesment-of-selected-fuels/

Available at https://www.sustainableshipping.org/wp-content/uploads/2021/09/Sustainability-criteria-of-marine-fuels-report.pdf

[4] Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels, Ricardo and DNV, April 2023.
Published in MEPC 80/INF.10 and available at https://www.imo.org/en/OurWork/Environment/Pages/Future-Fuels-And-Technology.aspx

[5] Zero Carbon Fuel Monitor, The Lloyd's Register Maritime Decarbonisation Hub, July 2022 update.
Available at https://www.lr.org/en/marine-shipping/maritime-decarbonisation-hub/zcfm/

It can be seen from Table 1 that the existing assessments focus on a specific set of criteria, for example technology or environment, and this is one area where the MTF Framework is proven to be more extensive in that it addresses all relevant criteria. These other frameworks (or assessments) also allow for comparisons to be made in terms of the evaluation outcomes of specific new technologies and energy carriers, thereby providing wider industry insight.

Table 1: Overview of other frameworks

Reference	Fuels/Technologies Addressed	Criteria Considered	Lifecycle	Comment/ Observations
IMO LCA guidelines – MEPC.376(80)	Fuel agnostic, 101 pathways	GHG reduction strategy (the third out of 4 strategy ambitions, as relevant here): uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030	Well-to-wake calculations related to production and use of marine fuels	None
The Nordic Roadmap project	Hydrogen, ammonia, and methanol, as well as methane, electricity in batteries, marine gas oil and liquefied natural gas	Environmental impacts (e.g. ecotoxity, human toxicity, acidification, land use)	Well-to-wake	Nordic context
The Sustainable Shipping Initiative	Any marine fuel – research presented is not specifically utilized for any given fuel	15 sustainability issues and criteria (e.g. emissions, air quality, water, food security, social)	Well-to-wake	Criteria available for use
Study on the readiness and availability of low- and zero-carbon ship technology and marine fuels	Biofuels, e-fuels, blue fuels (hydrogen and ammonia), electricity from the grid and fossil fuels blended with advanced biofuels and CCS	Technology (TRL) and Commercial (CRL)	Well-to-wake Distribution and storage Bunkering infrastructure	Feasibility analysis for meeting decarbonisation scenarios (modelled as 50%, 80% and 100% reduction by 2050
Zero-Carbon Fuel Monitor, LR	Re-electrofuels, natural gas with carbon capture and sustainable biomass-derived fuels	Technology (TRL), Investment (IRL) and Community (CRL)	Well-to-wake	Note separate report issued Sept-23 'The future of Maritime Fuels' presents fuel projections and demand/supply analysis
Zero Carbon Outlook, ABS	Hydrogen (spectrum of e- and blue fuels) and carbon (CCS)	Technology readiness, carbon economics, scaling	Well-to-wake	None
DNV Maritime Forecast to 2050	Technologies considered: solid oxide fuel cells, liquefied hydrogen, wind-assisted propulsion, air lubrication systems, onboard carbon capture, and nuclear propulsion.	Not criteria based	Well-to-wake	Addresses alternative technologies beyond the fuels considered in the other studies identified.

Using the Framework – Evaluation Process

The evaluation of fuels and technologies against the framework criteria is done by a team of specialists. Feedback is sought from all specialists evaluating the solutions under consideration. Based on this individual input, a workshop is conducted to aggregate the results and come to a consensus in terms of grading each criterion. The evaluation is performed using all criteria laid out in the framework. For each criterion, how well each solution meets the criterion, and the level of confidence are assessed. During the evaluation, the specialists make reasonable assumptions to complete the exercise. The opinions and options are based on their best judgement and expertise.

The process has been revised and clarified with regards to description of the scope of the solution, the evaluation grading levels, and the priority.

Scope

A key issue during the evaluation was to determine the scope and boundaries of the solution. For example, would onboard carbon capture, in combination with fossil MGO, also include aspects related to the delivery of the CO_2 and subsequent storage. Only when the scope is understood and clear to both MTF members and readers, can a consistent and valuable evaluation take place.

The solution should be clearly defined and described, and the evaluation should consistently include all relevant aspects from production, transport and storage, bunkering, onboard use and disposal. The scope is closely linked to GHG emission performance, and the scope should also define the expected level of emissions – for example e-ammonia with 70% well-to-wake GHG emission reduction compared to fossil fuels.

The solution can either be a specific technology – for example molten salt reactors – or a more general solution – for example onboard nuclear power – which can be achieved with several technologies. The scope should clearly define the approach and in case of addressing multiple technologies, the resulting GHG emission level should be similar.

Evaluation of the criteria

The original framework used three levels to assess how well a fuel met a criterion; meets criterion, meets criterion but can be improved, and fails to meet the criterion. The granularity for not meeting the criterion was considered insufficient as in many cases, it was expected that the solution could be improved in the future to meet the criterion. As a consequence, a fourth grading has been added, distinguishing between those solutions which can be improved and those that cannot be remedied.

For each criterion, the availability of data for evaluation and related epistemic uncertainty should be considered especially when assigning numerical scores which may be aggregated. A 'Confidence level' has been introduced to describe how confident the experts are that the evaluation is correct. This may highlight, for example, that a certain technology that appears economically unfeasible, may well be feasible once uncertainty is taken into account.

Some combinations of feasibility and confidence levels should be avoided. No feasibility assessment should be done where there is no availability of data. Areas with low feasibility and/or a low confidence level should be presented with an explanation for the assessment.

The updated gradings for assessing whether a fuel or technology meets each criterion, and the confidence level are shown in Table 2 below.

Table 2: Description of grading options for the feasibility and confidence level assessment.

Dimension	Grading	Description
Feasibility Assessment	High	The solution fully meets the criterion.
	Medium	The solution meets the criterion but can be upgraded further.
	Low	The solution requires significant developments to achieve the criterion, but is expected to be able to meet it in the future
	Not Feasible	The solution does not meet the criterion and is not expected to be able to meet it in the future.
Confidence Level	High	The data availability is high and there is robust evidence for the assessment.
	Medium	There is data available and there is medium evidence for the assessment.
	Low	The data availability is low and there is limited evidence for the assessment.
	Insufficient Data	Insufficient data means that no or limited data is available for evaluation against the criterion. In this scenario, reasonable assumptions should be made to complete the assessment.

Priority factor

A priority factor was initially used to weight the evaluation of each sub-criterion. The original aim of the priority factor was to bring the more important aspects to the fore. For example, reduction of GHG emissions could be considered more important than the current technology status. However, this did not have the desired effect as it was difficult to convey the priority to the reader. It also meant that the weighting would be determined by the framework, which may be different to that of the reader. The priority factor has been removed. Instead, the evaluation should be given as is, without any priority between sub-criteria. It is up to the reader to prioritize those aspects that are considered most important.

Review of the Criteria

The criteria have been reviewed on whether they are sufficiently clear and well-defined, overlapping with other criteria, as well as a structure and consistency across categories. Several criteria have been merged, deleted or moved. The explanations have been updated according to the changes or to make the text clearer. The methodology that were previously in a separate column have been merged with the explanation.

The well-to-wake GHG emission is the main goal for which the impact on other aspects is justified and is therefore now a standalone category. The GHG emission intensity should be provided as a numerical value, rather than using the feasibility grading. The Technology category has been elevated to sit just below GHG emissions, as this includes key high-level considerations of the solution across the supply chain. Security has been merged into one criterion and moved to Technology along with Supply chain resilience and Social acceptance. The technology readiness levels should be provided as a numerical value between 1 and 9.

The categories Environmental sustainability, Safety, Economic viability, Regulatory maturity and Skills availability are divided into the same four parts of the supply chain: production, storage and distribution; bunkering; onboard storage and use; and disposal.

The Engineering category relates only to the onboard technology and related interfaces such as shore power connection and does not include the engineering aspects related to the production of fuels for example.

Many aspects may be covered under multiple criteria. For example, regulatory complexity on bunkering would be included under the Regulatory category, but also potentially under Economic viability due to increased cost caused by the complexity. Where there was deemed to be duplication an effort was made to either combine the criteria or clarify the scope of the criteria to avoid overlap.

In addition to the literature review, the MTF framework criteria was further tested to validate that they are sufficient to capture current thoughts or concerns. Each team member of the working group separately provided their 5 key issues in terms of employing a number of different fuels and technologies: fossil LNG, fossil MGO and CCS, liquefied blue hydrogen, green ammonia, green methanol, biomethanol and biomethane.

Each fuel/technology was subsequently discussed to test whether the framework would prompt or capture all of the issues identified. This exercise validated that the criteria were extensive, while also highlighting some areas that required additional clarification within the criteria descriptions.

Table 3 lists the revised categories, while Table 4 lists the revised criteria and includes a note on the main change and rationale. In addition, editorial changes to the text have been completed, however, these are not explicitly noted.

Table 3: Revised categories

Category	Description
Greenhouse Gas Emission (GHG)	This is the main goal of applying the technology or energy carriers. The GHG emission is determined based on the solution as defined and described in the scope. All other criteria are evaluated based on this definition, assuming that the GHG emission criteria is met.
Technology	This is the general technology readiness and acceptance including all technologies across the supply chain. The technology readiness level is assessed based on today's status and the expected level in five years. In addition, this category include assessment on the social acceptance, resilience and security level.
Environmental Sustainability	This is the ecological and social impact (externalities). This includes topics such as toxicity, resource use (land, minerals, etc), water use or pollution (air/water etc), labour aspects such as welfare, health and equality and equity (in international aspects), etc. GHG emissions from CO_2, CH_4 and N_2O are not included as they are covered in a separate category.
Safety	This relates to the level of safety achieved, or can be achieved. This should also reflect the level of safety when scaling up from a single vessel to fleet-wide application.
Economic Viability	This relates to the cost of bringing the technology or energy carrier into service. The costs should also reflect the complexity when scaling up the use. Aspects related to availability of energy should be covered under Supply chain resilience.
Regulatory Maturity	This is the availability, maturity and complexity of implementing regulations. This includes consideration to the cost associated with that complexity, and compatibility between regulations and standards both across nations and within nations. This should be considered separate from maturity of a technology - e.g. where a electricity grid can be mature, but the standards for connections differ between countries. The confidence level should reflect the uncertainty that the regulation will become available in the future.
Skills Availability	This is the level of change that would be required, regarding the skill base and competency, in order to accept the new technology or energy carrier into service.
Engineering	This is the engineering aspects related to bringing the onboard technology or energy carrier into service. It also includes related interface technologies.

Table 4: Updates to the criteria

Category	Criterion	Explanation	Note on Changes and Rationale
Greenhouse gas emission	Greenhouse gas emission intensity	This is the well-to-wake GHG emission, measured in gCO_2eq/MJ, from the production, storage & distribution, use and disposal of the technology and/or energy carrier. It can be measured using ISO14040 on lifecycle assessment, the IMO LCA guidelines or the FuelEU maritime method.	The GHG emission intensity should be provided as a numerical value and determined based on the fuel and technology solution and described in the scope.
Technology	Current technology readiness level	This is the technology readiness level (TRL 1 to 9) at the time of assessment. The assessment should be based on the lowest TRL of all technologies across the supply chain.	The TRL should be a numerical value and specified to be based on the technology with the lowest TRL across the supply chain.
Technology	Expected technology readiness level in five years	This is the expected technology readiness level (TRL 1 to 9) five years from now on. This contributes to the assessment by informing of when technology may be available. The assessment should be based on the lowest TRL of all technologies across the supply chain.	The time horizon is specified to five years.
Technology	Social acceptance	This concerns the social acceptance of the technology or energy carrier in question, both in the industry and in the general public. It also includes whether is it aligned with other sectors in drive to decarbonisation, or misaligned.	This criterion is moved from People as it reflects the general acceptance of the technology both in the public and in the industry.
Technology	Supply chain resilience	This relates to resilience within the system (including within its supply chain and value chain) in relation to shocks and disruptions which can happen e.g. in the market, ecologically, as well as limitation due to availability and competition with other industries e.g. for fuel feedstock.	This criterion has been moved from the sustainability and environmental group as it relates to the high-level resilience of the technology and considered less related to sustainability and environmental. Aspects related to availability which was a separate criterion under Economic Feasibility have been included here.
Technology Readiness	Security against malicious actions	This relates to resilience within the system (including within its supply chain and value chain) in relation to shocks and disruptions which can happen e.g. in the market, ecologically, as well as limitation due to availability and competition with other industries e.g. for fuel feedstock.	This criterion has been moved from the sustainability and environmental group as it relates to the high-level resilience of the technology and considered less related to sustainability and environmental. Aspects related to availability which was a separate criterion under Economic Feasibility have been included here.
Environmental sustainability	Sustainability of production, storage and distribution	This is the ecological and social impact (externalities), arising as a result of production, storage and distribution scenarios.	Production, storage and distribution are combined into one criterion.
Environmental sustainability	Sustainability of bunkering	This is the ecological and social impact (externalities) arising as a result of bunkering scenarios, considering shore-to-ship and ship-to-ship bunkering.	
Environmental sustainability	Sustainability of onboard storage and use	This is the ecological and social impact (externalities) arising as a result of onboard storage and use scenarios.	To be consistent with other criteria the scope is specified to onboard storage and use.

Category	Criterion	Explanation	Note on Changes and Rationale
Environmental Sustainability	Recyclability and sustainability of disposal	This is the ecological and social impact (externalities) arising as a result of disposal scenarios. This includes the recyclability and waste aspects within production, when in service (via operation and maintenance), and to the end of life disposal.	
Safety	Safety during production, storage and distribution	This considers the level of safety achieved, and achievable, during production, storage and distribution.	Production, storage and distribution are combined into one criterion.
Safety	Safety during bunkering	This considers the level of safety achieved, and achievable, during bunkering, including all modes of bunkering.	
Safety	Safety during onboard storage and use	This considers the level of safety achieved during onboard storage and use (on the vessel). This includes all onboard use scenarios (underway, at anchor, in port, dry dock, etc), and includes operation and maintenance.	Onboard storage and use are combined into one criterion.
Safety	Safety during disposal	This considers the level of safety achieved, and achievable, during disposal.	
Economic Viability	Cost of production, storage and distribution	This relates to the cost of production, storage and distribution on land, and in total to the fuel cost.	The criterion has been restructured to align with the criteria of other categories.
Economic Viability	Cost of bunkering	This relates to the cost of bunkering.	The criterion has been added to align with the criteria of other categories.
Economic Viability	Cost of onboard storage and use	This relates to the cost of technologies installed on onboard for new construction projects, including energy storage and converters. The cost of the fuel or energy carrier is not included as this is covered by cost of production. It also includes indirect costs, including lost opportunity costs. Examples could be decreased range due to volumetric energy density and gravimetric energy density causing increased bunkering interval.; or location of storage tanks affecting cargo carrying ability.	Direct and indirect costs are combined into one criterion covering all onboard cost to align with the other categories. A clarification is added that the fuel cost is covered under cost of production.
Economic Viability	Cost of disposal	This relates to the cost of disposal of technologies and any waste or by-products.	
Regulatory Maturity	Maturity of regulations related to production, storage and distribution	This is the maturity and complexity of regulations relating to production, storage and distribution.	
Regulatory Maturity	Maturity of regulations related to bunkering	This is the maturity and complexity of regulations relating to bunkering	

Category	Criterion	Explanation	Note on Changes and Rationale
Regulatory Maturity	Maturity of regulations related to onboard storage and use	This is maturity and complexity of regulations relating to onboard storage and use.	
Regulatory Maturity	Maturity of regulations related to disposal	This is maturity and complexity of regulations relating to disposal.	
Skills Availability	Skill base and competency for production, storage and distribution	This is the level of change that would be required, regarding the skill base and competency within production, distribution and storage industry.	
Skills Availability	Skill base and competency for bunkering	This is to the level of change that would be required, regarding the certification & training for maritime industry personnel, including the availability across geographies.	
Skills Availability	Skill base and competency onboard storage and use	This is to the level of change that would be required, regarding the certification & training for maritime industry personnel, including the availability across geographies.	The name is changed to include the skill base and competency onboard in general, and not limited to certification and training. The explanation also specifies that is should include geographic availability of people in the maritime industry.
Skills Availability	Skill base and competency for disposal	This is the level of change that would be required, regarding the skill base and competency within the disposal industry.	
Engineering	Engineering complexity (production, installation, decommissioning)	This is the engineering complexity relating to bringing the onboard technology or energy carrier into service.	
Engineering	Complexity of retrofitting	This is the complexity of applying this in retrofit scenarios where existing safety arrangements could be unsuitable and the design is limited by space available (e.g. larger tank volumes are required for fuels with lower energy density, locating a contained fuel preparation space, accounting for larger piping, especially double-walled piping, may require pipes to be rerouted.	This criterion is moved from economic feasibility as it relates to the engineering aspects onboard.
Engineering	Availability	Availability is the measure of an item/ system's readiness for use (see IEC 60050-191). It is a function of the reliability and maintainability attributes of the system/item, and the level and effectiveness of the support arrangements in place. Preventative maintenance may be considered, as part of the availability calculation.For an item which is operating continuously, availability can be calculated as A = Uptime / (uptime +downtime).	The method description is integrated in the explanation.

Category	Criterion	Explanation	Note on Changes and Rationale
Engineering	Reliability	Reliability relates to an item/system working to its full capability (design capability) when it's required to.	
Engineering	Maintainability	Maintainability relates to the difficulty of repairing things once they have a problem. Therefore, it does not include preventative maintenance, but does incorporate the notion of corrective maintenance.	
Engineering	Logistics/ Supportability	This looks at the aspects required in order to support the item, including their complexity. For example, how simple is it to get support (parts, labour, etc) when in many worldwide locations, as well as constraints around that (cost, time, complexity, etc). This is - and affects - the supply chain, across all required locations and how complex that is (what is required to achieve it). But, more relating to the support supply chain, rather than initial production of the item. It can also include aspects such as consideration to connections for data for maintenance etc, diagnostics and calibration, etc.	
Engineering	Quality standards	This concerns safety aspects as a result of quality, as well as compatibility (internationally) as a result of quality, etc. This can apply for technologies and also energy carriers. E.g. when bunkering biofuel it needs to be according to a quality standard for engine compatibility and avoid corrosion, degradation.	The explanation is expanded with an example.

Table 5 lists criteria that have been deleted, noting the rationale and where the relevant aspects should be included. The list does not include criteria which have been combined or split due to align along the stages in supply chain across the categories.

Table 5: Deleted Criteria

Category	Criterion	Explanation	Note on Changes and Rationale
Safety	Aggregated safety considerations	The level of safety may be affected by the environment outside the vessel itself. This considers the level of safety achieved, and achievable, when you go beyond one singular vessel, such as when you look at multiple vessels in the same location (e.g. port, anchorage, etc). This criterion is more relevant to energy carriers, and less so to technology. Facets such as how energy carriers are stored and transported in the aggregated quantities, they need to be in are relevant in the overall safety consideration.	This criterion is deleted as these aspects are intended to be captured in the other criteria under Safety.
Economic Feasibility	Technical complexity of distribution	This is how technically complex it will be, to achieve distribution, in the quantities required.	This criterion is deleted as the complexity is captured under Technology Status, and any costs related to it should be captured under the other sub-criteria.
Economic Feasibility	Availability (quantity)	This is the availability, in terms of quantity. Depending on the technology or energy carrier, availability could be limited due to availability of an element within it. Cost to scale up availability would be included.	The criterion is deleted, and relevant elements are moved to Resilience under Technology Status.
Engineering	Interoperability	This concerns the interoperability surrounding the technology or energy carrier. For example, shore power connection compatibility, and fuel quality across countries.	This criterion is deleted as it is covered by compatibility of regulations and standards. The technology development related to interoperability is closely interlinked development and availability of standards.

Presentation of Evaluation Results

Presenting the evaluation of a single technology or energy carrier, and a comparison across multiple solutions are challenging as the categories and criteria cover a wide range of aspects, and the feasibility of two criteria may not be comparable as they carry different weight for different users. The priority of the criteria has been removed and it is up to the user to consider which items are more important. Consequently, the presentation of the results should facilitate that.

The evaluation of a single solution should start with a short and clear description of the scope of the technology and defining the expected well-to-wake GHG emissions. This is the starting point, and sets the boundaries for the remaining evaluation.

This definition of scope and boundaries should be followed by a compact visual summary of the feasibility and confidence levels. Numerical aggregation of the evaluations can be misleading and should be avoided. The aim should be to highlight areas with low feasibility and/or low confidence or lack of data. This includes where in the supply chain (e.g during bunkering or onboard use), and in which category (e.g. sustainability or safety). The supply chain stages have been aligned for all categories, except for GHG emissions and Technology Status, which are general across the supply chain, and for Engineering which focuses on the onboard technology and related interfaces.

The evaluation should conclude with a concise summary with reflections on the main findings, including the criteria with low feasibility and/or low confidence or lack of data. The complete assessment and any comments to each criteria evaluation should be included in an Appendix.

Several solutions can be compared side by side per criteria. Again, comparisons based on numerical aggregation of several criteria should be avoided, and the aim should be to highlight categories or criteria with low feasibility and/or low confidence or lack of data.

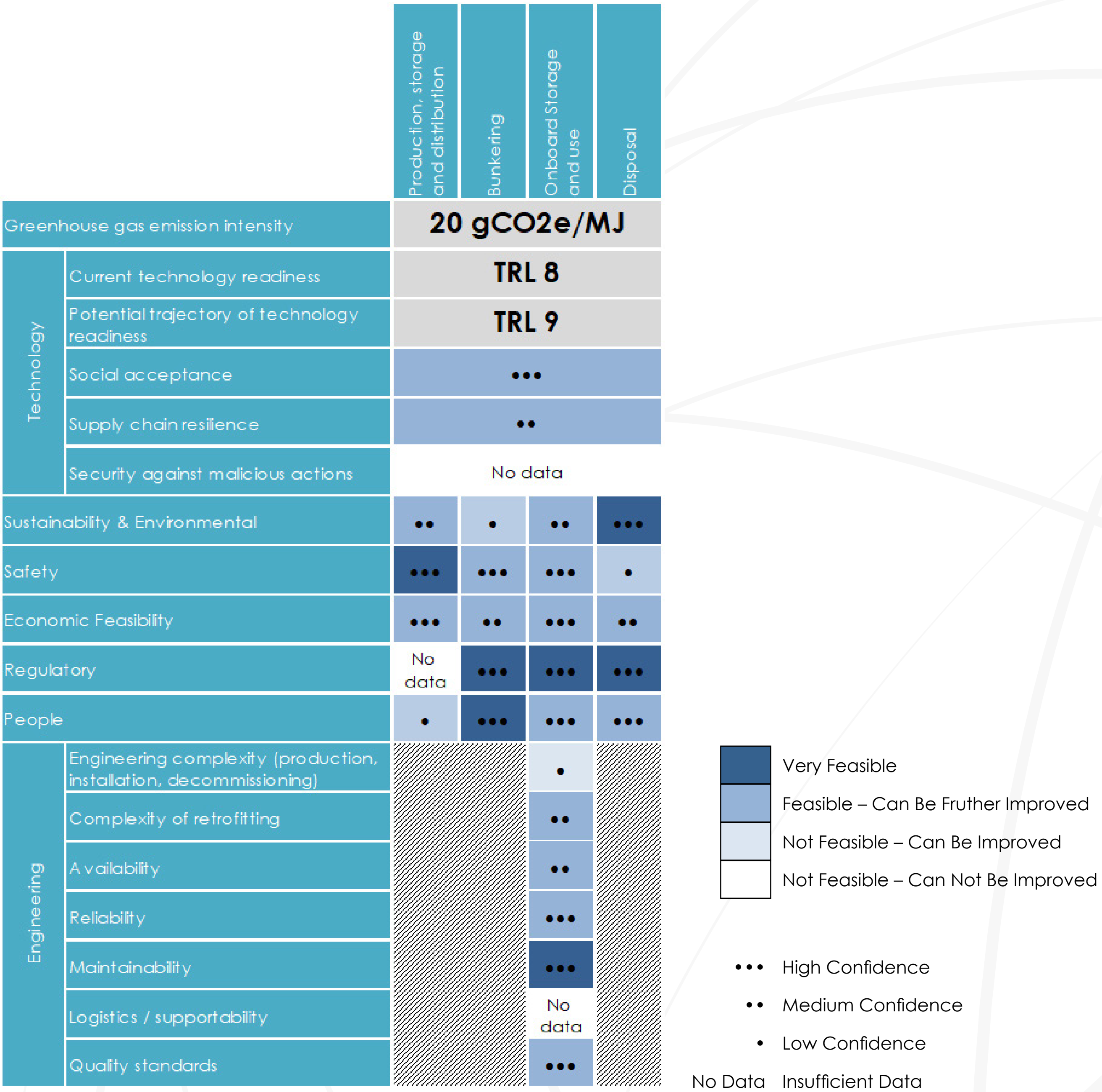
The following includes proposals for how the results can be visualized.

Sample Evaluation of a Solution

Solution: Short name of the solution.

Description: One paragraph defining the technology(s) and supply chain, and the boundaries of the evaluation.

Evaluation: The below provides an example of how the feasibility assessment and related confidence level can be visualized for a single solution. This is inspired by how IPCC conveys similar information GHG emissions and technology readiness levels can also be provided as numerical values. The feasibility is indicated by colors, using blue colors in this example as specified in the legend, although a color scale of red to green may also be used for instance to highlight areas with low to high feasibility. The confidence level is indicated by dots, or 'No data'. A variation of this would be to only indicate where there is no data or low confidence.



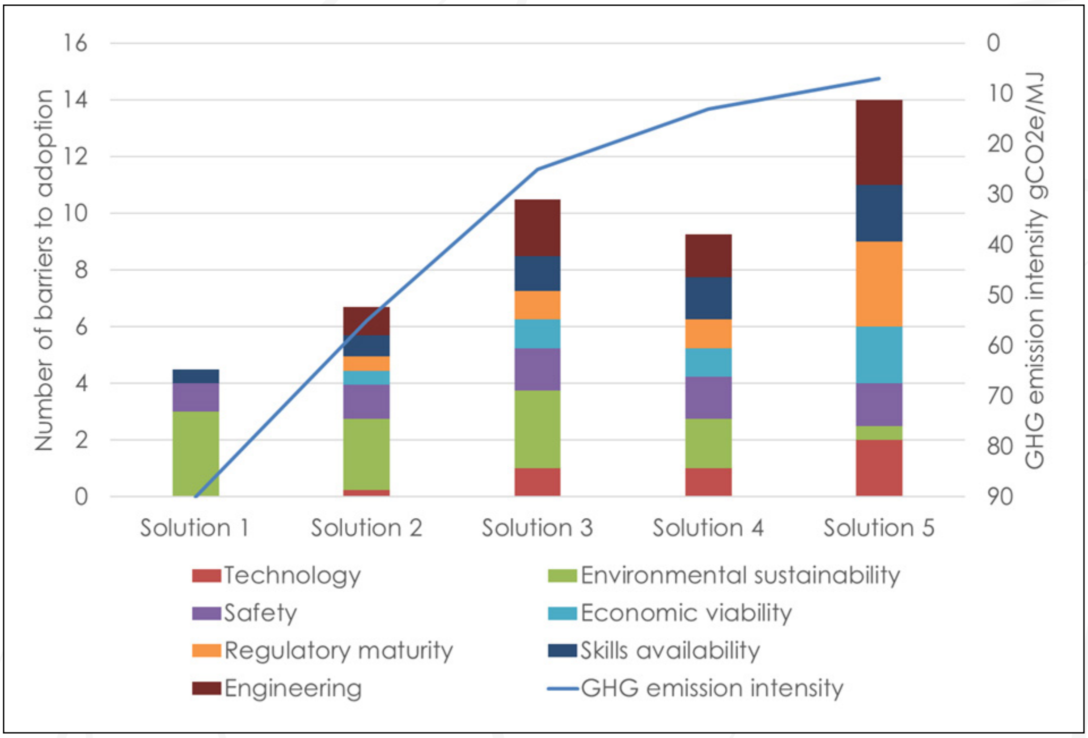
[7] See e.g. IPCC AR6 Synthesis Report, Figure SPM.7a: https://www.ipcc.ch/report/ar6/syr/figures/summary-for-policymakers/figure-spm-7/

The criteria where no data are available or graded to low feasibility and/or low confidence should be specifically listed with comments on the evaluation.

		Comment
Technology	Current technology readiness level	–
Technology	Expected technology readiness level in five years	–
Technology	Security against malicious actions	–
Regulatory Maturity	Maturity of regulations related to production, storage and distribution	–
Engineering	Engineering complexity (production, installation, decommissioning)	–
Engineering	Logistics/supportability	–

The below shows how a comparison between several solutions can be visualized. The first chart shows the number of criteria which are not considered feasible and/or where no data is available or assessed at low confidence. The second is a table using the same visualization per criteria as in the single solution example.

Sample Summary Chart



Sample Summary Chart

Category	Criterion	Solution 1	Solution 2
Greenhouse gas emission (GHG)	Greenhouse gas emission intensity	20 gCO2e/MJ	30 gCO2e/MJ
Technology	Current technology readiness level	TRL 8	TRL 6
	Expected technology readiness level in five years	TRL 9	TRL 8
	Social acceptance	•••	••
	Supply chain resilience	••	•••
	Security against malicious actions	No data	••
Environmental sustainability	Sustainability of production, storage and distribution	••	••
	Sustainability of bunkering	•	•
	Sustainability of onboard storage and use	••	•••
	Recyclability and sustainability of disposal	•••	•••
Safety	Safety during production, storage and distribution	•••	•••
	Safety during bunkering	•••	•••
	Safety during onboard storage and use	•••	•••
	Safety during disposal	•	•••
Economic viability	Cost of production, storage and distribution	•••	••
	Cost of bunkering	••	No data
	Cost of onboard storage and use	•••	••
	Cost of disposal	••	•••
Regulatory maturity	Maturity of regulations related to production, storage and distribution	No data	•••
	Maturity of regulations related to bunkering	•••	••
	Maturity of regulations related to onboard storage and use	•••	•••
	Maturity of regulations related to disposal	•••	•••
Skills availability	Skill base and competency for production, storage and distribution	•	•••
	Skill base and competency for bunkering	•••	•••
	Skill base and competency onboard storage and use	•••	•••
	Skill base and competency for disposal	•••	•••
Engineering	Engineering complexity (production, installation, decommissioning)	•	•
	Complexity of retrofitting	••	••
	Availability	••	•
	Reliability	•••	••
	Maintainability	•••	•••
	Logistics / supportability	No data	•••
	Quality standards	•••	••

Recommendation on Future Work

MTF has revised the evaluation Framework making it fit for purpose to address a wide range of solutions for decarbonization. The Framework presented in this report may need future revisions.

The existing evaluations based on the previous Framework are suggested to be revisited in light of the restructured criteria and the added granularity of the grading. It should not require a complete rework but can be built on the previous evaluation.

Further solutions should be evaluated, and existing evaluations should be regularly reviewed taking into account new developments.

Areas with low feasibility and/or no data or low confidence should be specifically addressed to improve the assessment and performance.

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