Statement of Work

Large-Scale Liquid Hydrogen Refuelling Station – modelling of potential market

Bucharest, March 25th, 2024

Organisation

Energy Policy Group Association (EPG) - www.enpg.ro - is a Romanian NGO, independent think-tank, specializing in energy and climate policy, market analytics and energy strategy, grounded in February 2014.

EPG is a research partner in the implementation consortium of the DelHyVEHR project (https://www.linkedin.com/company/delhyvehr/), an R&D project funded under the Horizon Europe framework. The project runs between January 1st, 2024 – December 31st, 2026 and its scope is the development (design, manufacturing, integration and assembly, prototype testing) of a large-scale liquid hydrogen refuelling station (LS-LHRS) to be used in a variety of applications, with a focus on heavy duty transport – aviation, maritime and railroad.

In the context of the DelHyVEHR project, EPG needs to perform an evaluation of the potential market for the LS-LHRS, between 2025 and 2050. As EPG does not have the tools to perform this market evaluation in house, the activity needs to be externalised.

Purpose and objectives

The purpose of the work to be undertaken under this SoW is the identification of the potential market size and market niches for the commercialisation of the product to be developed in the DelHyVEHR project, namely the large-scale liquid hydrogen refuelling station (LS-LHRS).

The main objectives of the analysis:

- **Objective 1:** Analyse the liquid hydrogen market (LH market), 2024 – 2050 timeframe
- **Objective 2:** Analyse the LS-LHRS market (main scope of the analysis), 2024 – 2050 timeframe

For **each of the two objectives/ LH & LS-LHRS markets**, perform the following:

- assess current (2024) and potential (2025 to 2050) market developments. For the LS-LHRS market study, the specifications of the station will be provided by EPG.
- identify relevant industries for the 2025 – 2050 timeframe:
    - for the LH market: identify relevant industries that will use liquid hydrogen and quantify the demand, the supply and map key players in the value chain
    - for the LS-LHRS market: identify industries in which such a station would be a good fit and quantify the need for LS-LHRS
- assess the market share per industry, per country (within EU-27) and per region, globally, between 2025 and 2050

In order to meet the two objectives, respectively market developments until 2050 a **market forecast** is required. Three forecasting scenarios will be considered, as a function of various criteria/indicators: (i) baseline, (ii) pessimistic and (iii) optimistic. The contractor shall select the criteria/indicators best suited

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for the forecasting. As a suggestion, liquid hydrogen price can be one such criterion. The contractor shall design the forecasting/market prediction methodology in line with its internal set of tools and procedures. The market forecast exercise shall be characterised by the implementation of a set of sensitivities, revealing the influence of the main assumptions on the final outcome of the analysis.

Deliverables

- one set of partial (draft) results, in the form of .pptx slides – by September 2024
- one set of final results, in the form of .pptx slides – by November 2024
- the final report containing the results and a description of methodology – by January 2025

More details on the deliverables are provided below.

Timeline

June 2024 (start of activity) – January 2025 (final report). A more detailed timeline is provided below.

Estimated value, payment terms and schedule

The total price of the activity shall not exceed EUR 55,000, all taxes included. A price lower than this shall be considered as an increased likelihood of obtaining the contract.

The payment shall be made by EPG by bank transfer, in Euro, directly in the account of the contractor, following the closure of the project. The contractor will issue an invoice, representing the legal basis of the payment.

The closure of the project will be decided by EPG following the evaluation of the final report against the acceptance criteria, as described in this document. The acceptance of the results and the closure of the project will be notified to the contractor by email, no later than 7 calendar days following the submission of the final report by the contractor (also by e-mail).

If needed, a provision can be made for the payment of the work in two tranches, as follows: a first tranche (no more than EUR 10,000), following the submission, by the contractor, of the preliminary results and second tranche, representing the payment difference, after the submission of the final report and acceptance of the results. In both cases, the payment shall be made by bank transfer, on the basis of an invoice issued by the contractor.

How to apply

The proposals shall be submitted by e-mail, to radu.cirligeanu@enpg.ro, between March 25th – April 30th, 2024. Following the submission, the applicant will receive a confirmation e-mail, acknowledging that the proposal has been well received and that it will be subjected to evaluation. Only the selected applicant will be contacted following the proposal evaluation period.

There is no proposal template. The applicant has the freedom to include in the proposal the information considered relevant for the application, in the format of choice.

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Additional information

Context

Project DelHyVEHR gathers 13 EU leading partners, from 6 different European countries covering the whole value chain from component development to system demonstration and assessment, along with an advisory board of worldwide leading hydrogen end-users. The project partners are:

- ENGIE (coordinator) – France (industrial entity)
- ELENGY SA (affiliated partner of ENGIE) – France (industrial entity)
- Ariane Group SAS – France (industrial entity)
- Fives Cryomec AG – Switzerland (industrial entity - SME)
- University of Ulster – UK (academia)
- Asociatia Energy Policy Group – Romania (NGO)
- European Research Institute for Gas and Energy Innovation – Belgium (Research & Technology)
- Absolut Hydrogen – France (industrial entity – SME)
- Dekkra Services SA – Spain (industrial entity)
- Benkei – France (SME)
- Trelleborg Clermont-Ferrance SAS – France (industrial entity)
- Trelleborg Sealing Solutions UK Limited – UK (industrial entity)
- CESAME-EXADEBIT SA – France (industrial entity – SME)

The end product of the project, the large-scale liquid hydrogen refuelling station, is fully in line with the European Union's decarbonisation strategy and fills a technology gap by developing a system that allows fast, reliable and efficient tank-to-tank transfer of large quantities of liquid hydrogen, thus facilitating a reduction in refuelling time and/or in the time required for loading/unloading large liquid hydrogen tanks.

Following project completion, the liquid hydrogen refuelling station is to be made commercially available. The identification of potential markets for this product is critical for the successful completion of the DelHyVEHR project. The technical, operational, economic and environmental characteristics of the station open up various commercialisation routes. At an early point of the project, one needs to identify what these routes are and to produce a roadmap for approaching the identified markets. The station will be made commercially available starting with 2029. A minimum commercialisation target of 15 stations in 2030 and 81 stations in 2040 is considered, serving the shipping, aviation and railroad industries worldwide. These estimations need to be updated and further substantiated.

Type of work

The work to be performed under the work package described in this Statement of Work (SoW) is an evaluation of the potential market for a high flow rate liquid hydrogen refuelling station. The analysis will cover the global market, with a focus on the European market (mainly EU-27). The results of the evaluation will contain a description of the current context – as a reference point (assuming the refuelling station would have been available by end 2023) and a forecast of the market evolution between 2025 and 2050, in increments of 5 years. The forecast will be produced by means of market numerical/analytical modelling using public data and (if needed) inputs made available by EPG (collected from consortium partners).

Parties involved

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The client is represented by EPG. EPG is a partner in the DelHyVEHR project implementation consortium.

The contractor is the institution performing the market analysis, in accordance with this SoW.

Once a contractor is selected, the collaboration between the two parties will be formalised in a contract to be agreed upon and signed by both parties.

Scope of work

This paragraph briefly describes the markets to be considered for the analysis (as a suggestion) and provides some guidance on how to approach the forecast methodology for certain activities. It is to be understood that all the information provided in this paragraph is for guidance only – the contractor shall have the liberty to take into account these suggestions or not.

Suggested markets

Several economic activities are identified as potential markets for the commercialisation of the liquid hydrogen refuelling station developed in the DelHyVEHR project. Each potential market is briefly described next, with some examples of applications for which the considered product might be of interest. These are markets in which liquid hydrogen plays (or will play) a central role.

The potential of each of these markets needs to be further analysed by the contractor, at global and European level. It is possible that some of the suggested markets prove not appropriate for the considered product. Alternatively, other markets, in addition to the ones listed in this SoW, could be identified by the contractor as potential markets for the liquid hydrogen refuelling station. The potential is represented by the need to manage large quantities of hydrogen in liquid form – either use the liquid hydrogen directly or convert gaseous hydrogen to liquid hydrogen for manipulation (storage, transport, transfer) and then re-convert it back to gaseous state utilisation.

1. **Market 1**: energy carrier for 4 types of transport

   This is the main market targeted by the DelHyVEHR project: heavy duty transport applications. Four transport types can be considered for this analysis.

   a. Commercial aviation

   Commercial aviation sector is one of the most difficult to decarbonise transport sectors due to extremely stringent mass constraints the onboard fuel needs to be subjected to. Although the energy content of hydrogen, per unit of mass, is three times higher than the energy content of kerosene, storing it onboard is a real technological challenge. Airbus [a1] is the flagship company having announced the development of liquid hydrogen powered aircraft to enter service in 2035. This development is accompanied by a sustained activity of developing the hydrogen infrastructure in the airports of tomorrow [a2] – Airbus is partnering with airports and local authorities for developing the network of airports that could serve the zero-emission aircraft in development now.

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Another major player in the liquid hydrogen aviation sector is Universal Hydrogen, a US-registered company developing hydrogen powertrains and on-board storage systems for regional aviation [a3].

There are three broad categories of entities to be looked at when putting together the pieces for the forecast of the future liquid hydrogen market in aviation:

- Aircraft manufacturers. The vehicles developed by these companies will need to operate on an airport infrastructure that today does not exist. The number of aircraft to be developed and their characteristics offer an indication of the future need of liquid hydrogen. Examples of companies: Airbus, Deutsche Aircraft, Cranfield Aerospace, Embraer, Avions Mauboussin, Electric Aviation Group, Aviation H2, Beyond Aero.
- Powertrain manufacturers. Examples: Universal Hydrogen, ZeroAvia, GKN Aerospace, H2Fly, MTU.
- Airports. Examples: Toulouse airport, Hamburg Airport.

A good starting point for the evaluation of the potential market for liquid hydrogen refuelling stations in the commercial aviation industry is the material prepared by the Aerospace Technology Institute (UK) – Fly Zero - Market Forecasts & Exploitation Strategy [a4].

Sources:

[a1] https://www.airbus.com/en/innovation/low-carbon-aviation/hydrogen/zeroe
[a2] https://www.airbus.com/en/newsroom/press-releases/2022-11-airbus-teams-up-to-advance-green-hydrogen-availability-at-airports
[a3] https://hydrogen.aero/
[a4] Aerospace Technology Institute (UK) – Fly Zero - Market Forecasts & Exploitation Strategy, March 2022.

b. Shipping

There are many examples of hydrogen powered vessels today, ranging from small vehicles for inland or close to shore operation to large ferries destined to transporting cars. If most small-sized ships are powered by gaseous hydrogen and fuel cell powertrains, with increasing ship size liquid hydrogen becomes more attractive. Even more so, if liquid hydrogen is readily available onboard, as in the case of the hydrogen carrier to be developed by Kawasaki (powered by gaseous hydrogen sourced from the liquid hydrogen transport tank) [b1] hydrogen becomes an obvious option as an energy source for the ship. Another example of vessel powered by liquid hydrogen is the MF Hydra, the first commercial passenger and car ferry fuelled by liquid hydrogen and owned by one of Norway's leading ferry and express boat operators, Norled AS [b2].

For long distance shipping, LNG seems to currently be the preferred fuel, as its combustion is much cleaner than the combustion of Diesel or heavy fractions of oil products and its onboard management is much simpler than the management of liquid hydrogen. However, the increasingly stringent emission restrictions (and prices of CO2) coupled with a continuous decrease in the price of liquid hydrogen and the development of the hydrogen refuelling infrastructure might indicate liquid hydrogen as the preferred fuel for a significant number of ship development projects. What is certain is that most Diesel powertrains currently in operation in the shipping industry will need to be replaced in the near future. This study should indicate how and if liquid hydrogen becomes the preferred fuel for this application.

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Sources:
[b1] https://global.kawasaki.com/en/corp/newsroom/news/detail/?f=20221130_6926
[b2] https://blog.ballard.com/marine/worlds-first-liquid-powered-hydrogen-ship-mf-hydra-is-powered-by-ballards-fuel-cells

c. Rail transport

Most of the hydrogen-powered trains developed or in development today rely on compressed gas hydrogen as an energy carrier. These are DMUs (Diesel Multiple Units) redesigned to incorporate hydrogen fuel cell powertrains. However, these trains are designed for relatively low speeds and limited range. Replacing gaseous hydrogen with liquid hydrogen is the next step in heavy-duty railway applications.

Examples:

- Wabtec is now developing a locomotive powered by an internal combustion engine using a mixture of Diesel and liquid hydrogen [c1]
- Hyundai Rotem is actively developing liquid hydrogen powertrains for railway applications [c2]
- The Korean Railroad Research Institute (KRRI) recently started a project for the development of a liquefied hydrogen-based traction system [c3]

Other manufacturers are developing LNG-based powertrains, as an intermediate step between the current situation (Diesel-powered locomotives) and fully liquid hydrogen powered trains.

One significant part of the market that needs to be investigated is the switcher (or shunter) locomotive market. These are locomotives used to manoeuvre railway vehicles over short distances. Most of these locomotives are currently powered by Diesel or electric powertrains. It is to be investigated, in this study, whether liquid hydrogen should be considered for these types of locomotives in the future.

Sources:
[c1] https://www.energy.gov/sites/default/files/2022-03/Liquid%20H2%20Workshop-Wabtec.pdf
[c2] https://tech.hyundai-rotem.com/en/green/hydrogen-railway-development-laboratory-of-hyundai-rotem-to-develop-safe-hydrogen-mobility%EF%BF%BC/
[c3] https://www.railjournal.com/technology/korean-project-to-develop-liquefied-hydrogen-fuel-cell-traction/

2. **Market 2**: liquid hydrogen transportation (loading/unloading tanks)

Irrespective of the final usage of hydrogen, unless it is generated on site, hydrogen needs to be transported from the point of production to the point of consumption. Depending on the amount of hydrogen and the distance on which it needs to be transported, this can be done:

- By pipes – as compressed gas, similar to how natural gas is transported today (not of interest for this study)
- By ship – over long distances, normally for intercontinental distances
- By train – over relatively long distances
- By truck – over short and medium distances

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When transported by truck, it can be transported both as a compressed gas and as a liquid, the latter being more energetically convenient for longer distances. When transported by ship or by train, in almost all the cases it is transported as a liquid. In such cases, high flow refuelling stations are required for transferring the liquid from the tank in which it is transported to the storage tank.

Liquid hydrogen transport needs will be evaluated and quantified in this work package. Both the quantities of hydrogen and the companies involved in the process will be identified.

Other markets shall be investigated, only if the contractor considers this appropriate AND the activity can be carried out within the allocated financial envelope:

- The industrial sector (e.g. production of ammonia, production of synthetic fuels, chemical industry, steel industry, other niche industries – like electronics)
- Space industry – refuelling of LH2/LOx space launchers (other than launchers developed and operated by Ariane Group)
- Special uses: large scale research facilities.

Suggested forecast methods

The development of novel technologies in any given industrial field often starts with the implementation of R&D projects (an example is the case of DelHyVEHR project). The completed and ongoing R&D projects in the field of liquid hydrogen utilisation are to be identified and evaluated, as these provide an image of the technological landscape of the future, even if this is not explicitly emphasised in the project. The R&D activity is to be correlated with the political ambitions mirrored in the national strategic documents.

For the transport of liquid hydrogen, the national hydrogen strategies will be studied for capturing the plans of hydrogen import/export. Based on the cost of transport, one will identify the situations in which there is a high likelihood of shipping liquid hydrogen from country A to country B, before being converted to gaseous hydrogen and injected into the national hydrogen transport network.

For the shipping and railroad industries, one will identify the projects that target the development of LNG-based powertrains, as a transitional element between Diesel (or other fossil fuels) and liquid hydrogen. Although the transition aspect might not be explicitly mentioned, it is to be inferred that part of the vehicles that are designed to operate on LNG are to be switched to liquid hydrogen when the economic conditions allow it.

Acceptable outcome

One will try to quantify the degree of uncertainty of certain market predictions, as a function of the accuracy of the input and the different assumptions made for the modelling. It is always desirable to know how likely a certain prediction is to materialise itself, so that the go-to-market strategy is adapted accordingly.

Uncertain predictions are acceptable, as long as this is properly highlighted and the reasons behind this uncertainty are clearly put forward.

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Proposed timeline- detailed

Date	Action
March 25th, 2024	Activation of the tender for contracting the market modelling services. The current Statement of Work, describing the work to be undertaken by the contractor is published on EPG's website (at www.enpg.ro). Entities willing to undertake work are allowed to submit a proposal without being specifically asked to do so.
April 30th, 2024	Deadline for proposal submission – end of business day (UTC + 2)
May 1st – May 10th, 2024	Evaluation of proposals
May 13th, 2024	The winning entity will be contacted (by e-mail) and informed about the positive outcome of the selection process. Only the winning entity will be contacted.
May 24th, 2024	The date by which the contract between EPG (as client) and the winning entity (as contractor) will be signed. Expected potential iterations before an agreement on the final form and content of the contract.
June 3rd, 2024	Kick-off meeting (online). Start of the activity.
June 21st, 2024	The date by which EPG will share with the contractor all the required input for the analysis.
September 2nd, 2024	The contractor will make available the first version of the draft analysis' results, in the form of .pptx slides. An intermediate review online meeting will be set for the same day – the contractor will present the first version of the results.
September 13th, 2024	EPG will provide feedback on the results: questions, request for clarifications, suggestions for improvement.
September 16th – 20th, 2024	If needed, a meeting (online) will be organised with the contractor for further discussions / clarifications on EPG's feedback and proposed way forward
November 29th, 2024	The contractor will make available the revised set of results. These represent the final results of the analysis. The results will be provided as .pptx slides.
January 31st, 2025	The contractor will submit to EPG a report comprising: the results, a description of the modelling/analysis methodology, uncertainty evaluation, inputs, modelling hypotheses, etc.
February 21st, 2025	EPG will provide feedback on the acceptance / need for revision of the report. If the results are accepted, the project is considered closed.
February 28th, 2025	The contractor needs to issue an invoice for the overall price of the activity, in line with the financial terms and conditions set in this SoW and further described in the contract.
March 14th, 2025	The date by which EPG will have to pay the invoice received from the contractor.

Notes:

- The dates indicated in the timeline are flexible
- If necessary, the second part of the study (following the provision of the intermediate results) can be extended.

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Deliverables- detailed

The following deliverables are expected as output of the proposed work:

1. Preliminary set of results*, in the form of .pptx slides, by September 7th, 2024. The results will also contain a brief overview of the market modelling methodology and the set of assumptions and inputs used for the analysis. The results are to be sent to EPG by e-mail and further detailed and explained in a dedicated online meeting. These results must:
    - show good progress of the activity
    - contain all the required output (as described in paragraph **Purpose and Objectives**) at a level of detail that needs further refinement OR
    - contain part of the output (as described in paragraph **Purpose and Objectives**) at the final level of detail
2. Final set of results*, in the form of .pptx slides, on November 29th, 2024. As for the intermediate results, these will contain a brief overview of the market modelling methodology and the set of assumptions and inputs used for the analysis. The results are to be sent to EPG by e-mail. These results must be self-contained, in the sense that without additional, explanatory material, one must be able to make use of the data included in the slides. The results are to be sent to EPG by e-mail and further detailed and explained in a dedicated online meeting.
3. The final report, in pdf format, incorporating the results* of the analysis along with:
    - A description of the modelling methodology
    - The inputs used in the modelling
    - Other assumptions and hypotheses considered for the modelling
    - An indication of the uncertainty of the results

* by results, one understands the market assessment (worldwide and within Europe), between 2025 – 2050, in increments of 5 years, a repartition of this market by industries and by regions (at global level) and by countries (for Europe). Also, the sensitivity analysis showing the impact of the most relevant inputs/assumptions on the market repartition is to be considered as part of the results.

Quality evaluation and acceptance criteria

One of the first indicators of the quality of the work performed by the contractor is a detailed explanation of the methodology, inputs and assumptions. A good understanding of these three aspects allows EPG to evaluate the robustness of the forecast. The contractor shall clearly state in the proposal what the limits of communication are, with respect to its internal processes and methodologies. If needed, a non-disclosure agreement (NDA) can be signed between the contractor and EPG. Consequently, the contractor can indicate the pieces of information that can be disclosed to EPG under the NDA (for facilitating understanding) but cannot be made public.

Criteria of acceptance for the deliverables:

- Completeness. This indicates the degree by which the submitted results cover the requirements of the work package, as laid down in this SoW
- Degree of justification. This indicates the amount of explanation provided for each set of data/result so that EPG can understand the mechanisms that led to this result. In addition, this

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indicator reflects the robustness of the arguments brought forward by the contractor for supporting any given assumption
- Degree of realism. This indicates whether any given dataset (or result), as produced by the model, is realistic, given the economic, geographic, financial, political, environmental, social (etc) context. This indicator heavily relies on common-sense.
- Trustworthy sources of information and references
- Validation of the forecasts by a back-to-back comparison with external, independently generated forecasts on a certain aspect. As an example, when forecasting the market repartition for liquid hydrogen in the aviation sector for the European countries, the dataset is considered as validated if a similar forecast (external, independently produced) is identified for just one country.

The proof of acceptance of any given deliverable (either intermediate or final) is a written confirmation sent to the contractor, by e-mail, by EPG.

Proposal selection criteria

The proposals submitted by each applicant will be analysed by EPG in the evaluation phase, immediately following the closure of the proposal submission period.

The applicant needs to be registered in the EU or to have a working office in one of the EU member states. Applications from organisations that do not fulfil this criterion will not be considered.

Three criteria will be considered in the evaluation of proposals submitted by eligible applicants: the quality of the proposal (50% weight), the experience and qualifications of the applicant (25% weight) and the price (25% weight).

Quality of the proposal

The following indicators will be used for assessing the quality of the proposal:

- the degree of completeness – indicating the extent to which the proposal addresses all the objectives of the work package.
- the degree of granularity – indicating the level of detail characterising the results
- forecast accuracy – indicating how trustworthy the projections will be and under which assumptions
- methodological robustness – the description of the modelling methodology to be used is considered representative for the good quality of the analysis

Applicant's experience and qualifications

It is important for the applicant to be able to demonstrate experience in the field of the proposed work. This experience can be substantiated by:

- published (and peer reviewed) studies in a similar field or having implemented a similar market analysis method
- examples of past (or ongoing) contracts/projects in which the applicant is advising a company, a governmental agency or other type of institution in producing a clear vision of the future market in connection to energy, transportation or green hydrogen topics

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- proof of past sustained activity in the field of market modelling, in the field of (but not limited to) hydrogen technologies

The qualifications of the applicant will be assessed by:

- the availability of, or access to, a numerical or analytical tool able to predict the market evolution for the aspects relevant for this work package
- personnel that are specialised in market analysis and knowledgeable of the field of hydrogen economy, in general, and liquid hydrogen, in particular
- existence of other in-house tools, processes, methodological approaches that weigh in embedding quality in the work to be done

The applicant is encouraged to include in the proposal elements that shed light on these two aspects, for increasing their chances of obtaining the contract.

Price

Although a maximum limit of EUR 55,000 (all taxes included) has been considered for the price of the work package, a lower offer is always desirable and advantageous for the applicant in the proposal evaluation process.

Intellectual property

The data produced by the contractor, in the framework of this work package, will become the property of the client (EPG). Although not owner of the data, the contractor still has the right to use the data for personal needs, under the obligation of acknowledging that the data was produced as a result of work undertaken and paid for by EPG.

EPG will have the right to make use of the data produced by the contractor in the framework of this work package, by specifying that the data was produced by the contractor for EPG. EPG can use this data either for justifying its activity in the DelHyVEHR project or for internal research/studies.

The data produced in this work package will become public.

By data produced by the contractor, one should understand the following types of information:

- graphs, charts and other forms of graphical representation of information
- numerical data representing market segmentation, per industry and per region (or country), the product being represented by the high flow rate liquid hydrogen refuelling station
- the sensitivity of market segmentation to the main inputs / assumptions used in the study

The data owned by the contractor and developed prior to the signature of the contract with EPG will remain the property of the contractor. Non-exhaustive examples of data falling in this category:

- sensitive details about the market model and modelling techniques
- databases used for sourcing information (if not public)

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Document approval

Contractor (full name of the organisation)	
Contact person	
Full name:	
Role:	
E-mail address:	
Signature:	
Date:	

Client (full name of the organisation)	
Energy Policy Group Association	
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Signature:	
Date:	March 25th, 2024

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