The case for methane capture at hydropower dams

L. Parlons Bentata and N. Rueda-Vallejo, Bluemethane, UK

This paper seeks to understand the levels of awareness of methane and other GHG emissions across the hydropower community, to evaluate why methane capture and utilisation strategies have not yet been developed, and to what extent there is a case for methane capture and utilisation at hydropower dams. The study aims to determine awareness levels of GHG emissions from hydropower reservoirs among the global hydropower community, assess awareness levels of existing methods used to measure, monitor and mitigate GHG emissions and explore the enablers of methane mitigation strategies.

Accounting for 17 per cent of global generation and 70 per cent of all current renewable energy [IEA, 2021[1]], hydropower remains a cornerstone in the clean energy transition. To reach the IEA suggested Sustainable Development Scenario, hydropower needs to increase by 3 per cent per year until 2030 and to double by 2050 [IEA, 2021[1]; Zarfl *et al.*, 2015[2]]. Relative to fossil fuels, hydropower offers substantially lower greenhouse gas (GHG) emissions per unit of energy generated, and lifetime emission levels comparable with emissions from other renewable energies including wind and solar [Zarfl *et al.*, 2015[2]; Berga, 2016[3]; Almeida *et al.*, 2019[4]; Dos Santos *et al.*, 2004[5]; St. Louis *et al.*, 2000[6], Demarty and Bastien, 2011[7]].

Despite hydropower's carbon footprint being comparable with other renewable energies and considerably lower than most large-scale generation options, reservoirs can be a significant greenhouse gas source, emitting about 1×10^9 tonnes of greenhouse gases every year [Yang *et al.*, 2014[8]; Deemer *et al.*, 2016[9]], representing 1.3 per cent of total annual anthropogenic global emissions. Among these emissions, hydropower reservoirs emit an estimated 22×10^6 tonnes of methane [Harrison *et al.*, 2021[10], Deemer *et al.*, 2016[9], Scherer and Pfister, 2016[11]; Ocko and Hamburg, 2019[12]] from the anaerobic decomposition of organic matter on land flooded when the reservoir was constructed, or from river runoff, or brought into the river flow from upstream.

Methane's 100-year global warming potential is 34 times greater than carbon dioxide [UN IPCC, 2014[13]], which makes it an attractive target for climate mitigation policies [UN IPCC, 2021[14]; Boucher *et al.*, 2009[15]]. While a nascent discipline, there is an accelerating increase in literature focused on understanding more about GHG emissions, and in particular methane, from hydropower dams [St Louis *et al.*, 2000[6]; Soumis *et al.*, 2005[16]; Fearnside, 2016[17]; Dos Santos *et al.*, 2006[5]; Fearnside *et al.*, 2012[18], 2016[17]; Delmas *et al.*, 2001[19]].

Increasing interest in GHG emissions from hydropower dams has promoted their measurement [Soued and Prairie, 2020[20]; Harrison *et al.*, 2021[10]]. Given climate change dynamics, international sustainability initiatives from bodies like the Hydropower Sustainability Protocol have called for greater inclusion of GHG emissions measurements during the entire lifecycle of the dam. Beyond measurement, the predominant approach for methane mitigation remains biomass clearance, although less effective than previously believed, with recent interest in engineering solutions including floating intakes or alternative approaches to increasing oxygen circulation.

As it is not yet possible to avoid or mitigate all GHG emissions from reservoirs, carbon capture and utilisation is an alternative technological solution. Many commercial carbon capturing solutions are already in operation or under development [Biniek *et al.*, 2020[21]]. These carbon capture technologies are oriented towards atmospheric carbon dioxide removal which, because of the low atmospheric concentrations, make it a very energy and capital-intensive process. Unlike carbon dioxide, methane is an energy source which is continuously produced at the reservoir, therefore capturing and processing methane could offer many environmental and financial rewards [Lima *et al.*, 2008[22]; Ramos *et al.*, 2009[23]]. Initiatives to capture and utilise methane from water include KivuWatt, a powerplant operating at Lake Kivu (DRC/Rwanda) using captured methane from the lake, and Spannenburg, a drinking water treatment plant in the Netherlands capturing and utilising methane from groundwater. Other researchers are working on membrane technologies, including methane-water degassing, which could be suitable to capture methane from freshwater bodies such as peatlands [Heile *et al.*, 2017[24]; Bartosiewicz *et al.*, 2021[25]].

While there is a growing body of literature on enabling factors to reduce GHG emissions from other energy sources, few are specifically focused on hydropower. Examining enablers in other well documented industries, where waste materials are being reused sustainably as a valuable resource within a circular economy, can serve as a basis for categorising enablers of GHG emissions reduction at hydropower dams [Forrest *et al.*, 2021[26]]. Assessing the role that these enablers play contributes to understanding what practices are needed to reduce GHG emissions from hydropower reservoirs. For clarification, when this paper refers to hydropower dams, it refers to hydropower reservoirs and associated hydropower infrastructure.

1. Research design and method

1.1 Research approach

A literature review was undertaken (in English) to understand levels of awareness of GHG emissions from hydropower. While searching through academic literature and non-academic online sources, no studies were found to examine awareness levels of GHGs within the hydropower industry. Therefore, the authors undertook primary research.

Table 1. Distribution of survey respondents by stakeholder	
Stakeholder	Number of respondents
Energy company (including dam owners, operators, integrated energy companies)	121
Engineering, procurement and construction company	64
Technical advisor or consultant	63
Academic	33
Environmentalist	18
Industry associations	14
Financier or investor (including development banks, banks, pension funds, private equity, venture capital	12
Government (agency or ministry)	12
Non-governmental organisation (community, not-for-profit)	9
Policy maker or regulator	7

This primary research combines quantitative and qualitative methods to contribute to understanding better the research topic. A quantitative survey was used to collect as many responses as possible to assess most parameters and assumptions. Subsequent individual virtual semi-structured interviews were used to elicit deeper insights and to explore perceptions, feelings, and understanding. Data were collected during July and August 2021.

1.2 Data collection

Online survey

The online survey consisted of 15 questions, including 13 closed and two open-response questions, was available in four languages and was designed to be completed within ten minutes. Prior to public circulation, the survey was reviewed by five industry experts and piloted with five hydropower experts. An online market research platform was used to deliver the survey and collect the data. To access the global hydropower community, the authors contacted members of the International Hydropower Association community and also used social media platforms. 239 participants with professional experience within the hydropower industry completed the online survey. These participants represented stakeholders across the hydropower value chain (Table 1) with experience of hydropower projects in 84 countries.

Follow up interviews

The final survey question asked respondents whether they wanted to participate in a follow-up virtual video interview, available in four languages. Of the 239 survey participants, 89 agreed to take part in interviews. From this subset, 30 participants booked times for interviews, and 18 semi-structured interviews were conducted, each completed within 25 minutes. Interviews were recorded, transcripts were created using a transcribing software, and subsequently analysed.

1.3 Potential limitations of research design

The potential limitations associated with the data collection method which could impact whether the findings are representative of the total hydropower community include (but are not limited to):

• Access to survey respondents being sourced from limited channels.
• Self-selection bias:
  o the possibility that members of hydropower associations were already more attuned to the subject matter than non-members;
  o those with an interest or knowledge about GHG emissions were more likely to complete the survey,
  o only those who were particularly focused on the GHG topic would put themselves forward for the follow-up interview,
• The limited sample size of 239 participants and 18 interviewees could have missed additional views or themes.

Despite these methodological limitations, the authors believe engaging with the research participants who are likely to be in positions to implement some of the research recommendations is beneficial in mitigating GHG emissions from hydropower.

2. Results and discussion

2.1 Awareness levels of GHG emissions from hydropower reservoirs among the global hydropower community

Of the 239 survey respondents, 85 per cent were aware that hydropower dams emit significant GHG emissions (Fig. 1) with more than half of the total respondents being aware of either methane (73 per cent of respondents) or carbon dioxide (69 per cent of respondents) being emitted (Fig. 2).

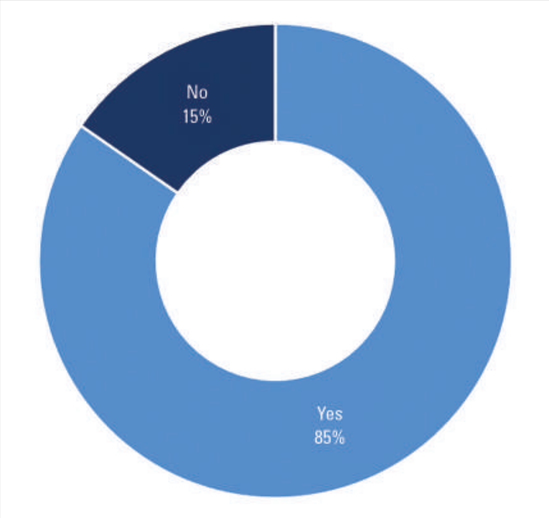


Fig. 1. Awareness of GHG emissions in general from hydropower dams, among hydropower stakeholders.

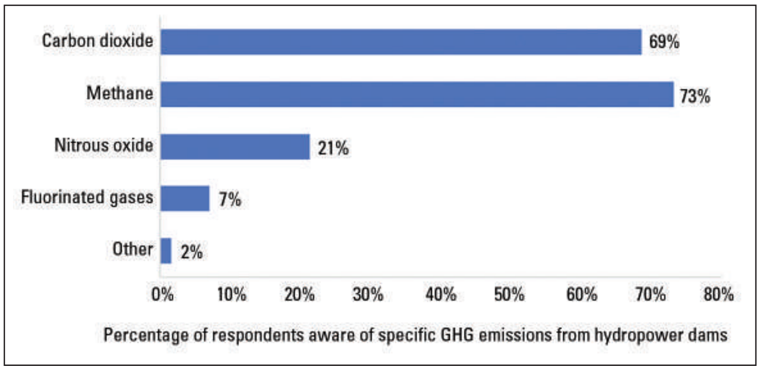


Fig. 2. Awareness of the specific gases being emitted from hydropower dams by the stakeholders.

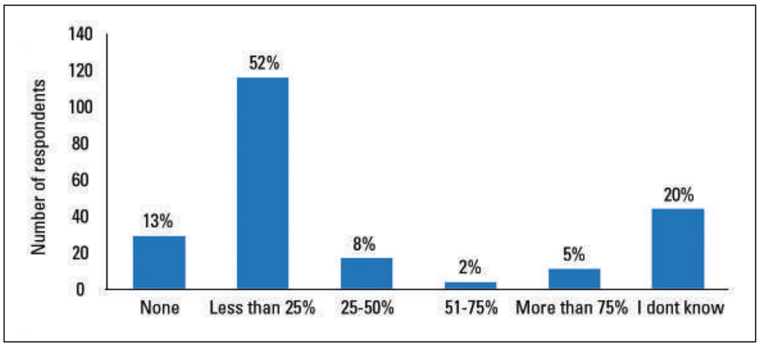


Fig. 3. Proportion of hydropower projects estimated to be measuring GHG emissions.

Despite the relatively high awareness of methane and other GHG emissions from hydropower, these emissions are not widely measured. The majority of survey respondents estimate that less than 25 per cent of hydropower projects measure their GHG emissions (Fig. 3).

Interviewees recognized that measurements are needed to develop insights, understand the scale of the problem, and enable tools to mitigate and reduce GHG emissions. "Data are always power. The more emissions data we can collect, the more insights and the better our understanding of the scale of the impacts. Then we can develop the best mitigation and policies to deal with it" (from Interview D).

2.2 Awareness of methods used to measure and monitor GHG emissions

There is low awareness of GHG measurement initiatives with many survey respondents being unsure about the measuring techniques available. When provided with a list of measuring initiatives to select from, even the most well known measuring techniques (G-Res and direct sampling) were known by only a third of respondents. (Fig. 4).

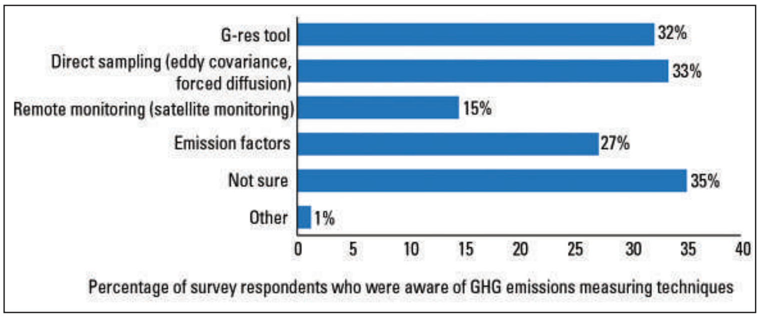


Fig. 4. Proportion of survey respondents aware of GHG emissions measuring techniques.

With different measuring methods being adopted by dams, interviewees believed it was challenging to scrutinise results, resulting in some level of dispute about the accuracy of GHG emission levels. Some interviewees mentioned that uncertain and uncalibrated GHG measurements were slowing down the development process at potential new dam sites. "Whenever there is a new project, there is a lot of pressure for the developer to manage the emissions from the reservoirs. The opposition is always using the unknown about the reservoirs emissions to try to stop the project happening" (from Interview E).

Part of the challenge seems to be the lack of baseline emissions measurements taken before the reservoir is filled. Without this comparative footprint, it is more difficult to understand the net footprint (change in emissions), or to compare different reservoirs, or to compare hydropower with other energy sources to show how sustainable hydropower is. "If hydropower had accurate measurements, we could show how green it is versus other energy sources. Without accurate measurements, hydropower can get a bad reputation relative to other energies" (from Interview F).

2.3 Awareness of strategies to reduce GHG emissions at hydropower dams

For this open response question, participants cited a broad range of strategies to prevent or reduce GHG emissions. These were organized into six categories (see Table 2).

Overall, vegetation clearance to remove organic matter was the most frequently cited strategy to reduce GHG emissions. While recognized by respondents as having the largest impact on emissions levels, interviewees noted the complexity in determining the correct amount of biomass to remove, mentioning the need for further studies to model the proportion of vegetation removed with soil stability and GHG emissions. "We need to balance the requirement to cut and remove the vegetation and stabilize the slopes. You

Table 2. Awareness of solutions to reduce GHG emissions at hydropower reservoirs

Category	Examples of strategies	Number of responses
Environmental	Planning & design considerations (increase depth and reduce surface area of reservoir, favour run-of-river power plants), better site selection (colder environments), deforestation before impoundment, afforestation/stopping deforestation, buffer zones, vegetation treatment/removal, treatment of dammed water/sedimentation management.	155
Technological	Improved technology (e.g. scrubbers, electrostatic precipitators, filters), mapping/monitoring of methane emissions, improvement and careful operation of equipment, methane capture, flaring storage and utilisation, ensuring intake level is above the thermocline/hypolimnion, adapting inlet position, covering the reservoir/black floating balls/integrating on-site renewable technologies, proper aeration/water circulation.	66
Political	Stricter environmental policies	3
Financial	A circular economy approach, offset emissions using carbon credits	3
Social	Increasing awareness of methane emissions at dams	4
Don't know	Don't know, focusing efforts elsewhere. Very little/nothing can be done	48

cannot always remove everything" (from Interview L). While most respondents believe the main source of methane is from the flooded vegetation, this is not the case. Most methane is derived from carbon in the soil.

Beyond vegetation removal, a wide range of technical solutions were cited in the survey. However, there was low awareness of each of these suggested mitigation solutions among survey respondents. About 25 per cent of respondents reported not knowing any strategies to reduce GHG emissions at hydropower dams. The 66 technological suggestions were at various levels of technical readiness from well understood adaptations to the intake level or more expensive aeration technologies in pilot phases. Methane capture, flaring, storage and utilization are in the ideation phase and were suggested by four respondents.

2.4 Benefits of reducing GHG emissions at hydropower dams

Survey respondents force ranked five given benefits associated with reducing GHG emissions (see Fig, 5).

The benefits of reducing emissions were considered primarily environmental. Interviewees explained these environmental benefits referred to the contribution to net zero emissions targets. The second highest ranked benefits were reputational. Interviewees explained these as both corporate and industry reputational benefits. Interviewees detailed how GHG emissions mitigation could accelerate hydropower's development. "The question mark around reservoir emissions is probably one of the main aspects that is slowing down the development of hydropower" (from Interview E). However, 74 per cent of survey respondents believed that if GHG emissions were ignored at hydropower dams, there would probably be increased reputational risk (Fig. 5).

The financial benefits of reducing GHG emissions are ranked low (Fig. 6). There seems little perceived financial incentive to achieve these environmental benefits. However, there is a disconnect, as 64 per cent of respondents believed that if GHG emissions are ignored, they will have difficultly accessing finance and 50 per cent believed they would need to pay carbon taxes if these emissions are ignored (Fig. 6).

"We need to implement policies or financing criteria to force owners and financiers to mitigate their GHG emissions, even if they don't want to." (from Interview D). "If climate bonds can offer an attractive interest rate compared with other financing tools for projects unable to fulfil the strict sustainability assessment requirements, that will be another driver for hydropower developers to go for sustainable hydropower" (from Interview N).

2.5 Awareness of enabling factors to reduce methane emissions

To identify the most influential enablers to achieve a reduction in methane emissions, interview transcripts were coded in accordance with key enablers identified in literature related to another industry where waste materials were being considered as a valuable resource. The results of this coding are detailed in Fig. 7.

During interviews, financial incentives were the most frequently cited enabler and considered to be the most influential factor to reduce GHG emissions at hydropower dams, followed by legislation and measuring and monitoring (Fig. 7). Beyond these more frequently cited enablers, many other factors were also mentioned.

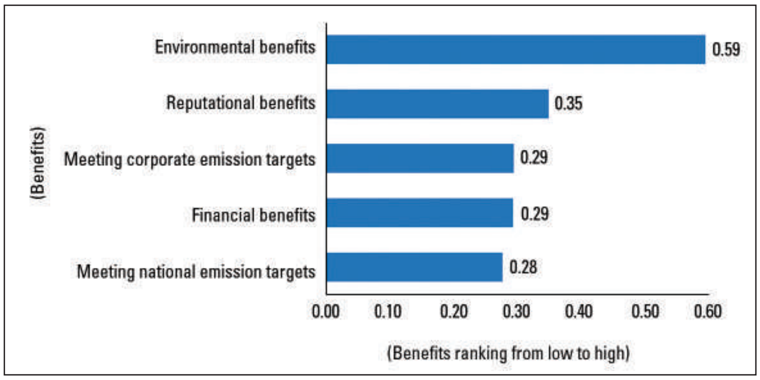


Fig. 5: Ranked benefits of reducing GHG emissions at hydropower reservoirs.

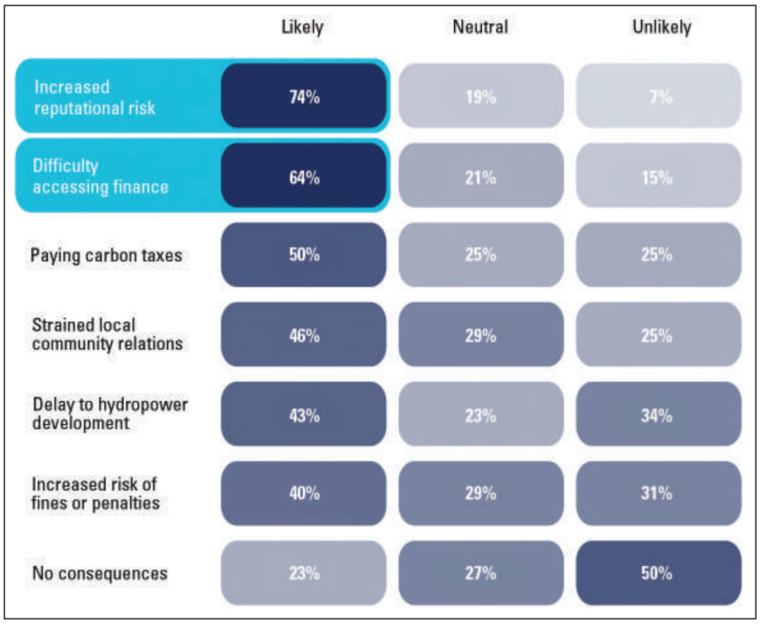


Fig. 6: Likelihood of alternative scenarios if GHG emissions at hydropower reservoirs are ignored.

To understand where hydropower stakeholders thought the ownership lies for the reduction in GHGs, survey respondents were asked whether they think that hydropower operators were responsible for reducing their GHG emissions. 84 per cent of the 239 survey respondents thought that operators have a responsibility to reduce GHGs at dams (Fig. 8).

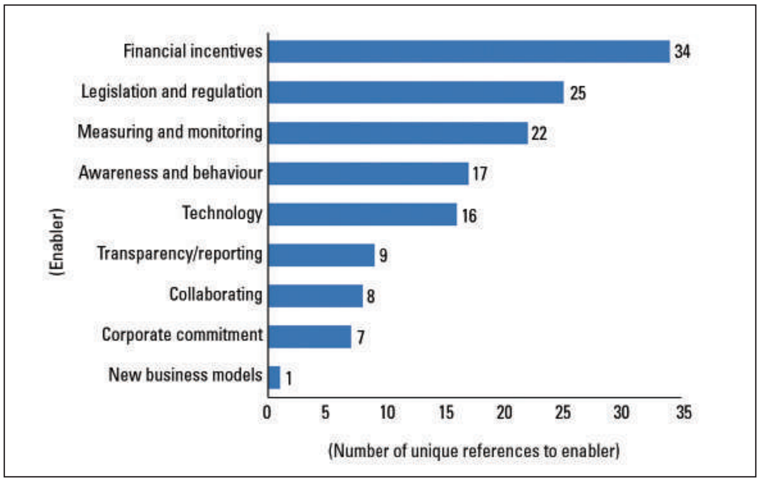
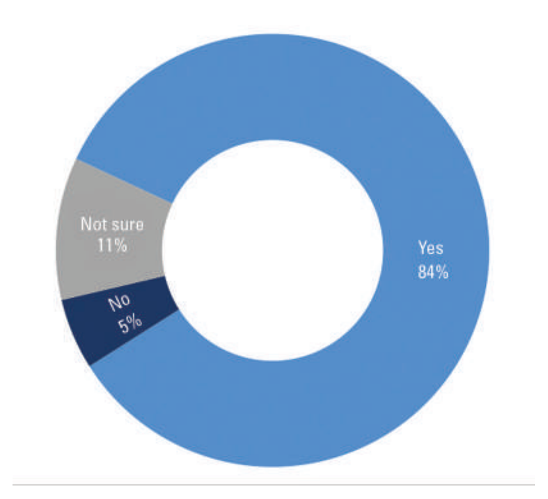


Fig. 7: Frequency with which enablers were referenced by hydropower stakeholders during the interviews.

Fig. 8. Survey respondents' thoughts on whether hydropower operators have a responsibility to reduce GHG emissions.



However, interview respondents recognized that operators needed defined financial motivation to measure and mitigate methane emissions, and that these need to come from the banks, dam owners, national governments and industry guidelines. "If there is financial or commercial motivation behind these activities, we will have more success in greenhouse gas reduction in hydropower plants" (from Interview Q).

3. Conclusions

The engaged hydropower community is largely aware of GHG emissions from hydropower dams, in particular methane and carbon dioxide. Despite this, emissions are not widely measured and there is low awareness of GHG measuring techniques, with the most frequently employed measuring approaches being recognised by only a third of respondents. The lack of industry standards for the measuring and reporting of GHG emissions can result in the slowdown of the project development process.

Removing vegetation prior to impoundment was the most widely known methane mitigation measure among survey respondents (despite it not being an effective technique). Multiple alternative technical solutions were suggested, at different technological readiness levels and financial viability, but each with very low awareness. Methane and other GHG capture technologies were hardly mentioned.

Although the benefits of reducing GHG emissions were considered primarily environmental, the hydropower community believe that taking no action to reduce these emissions could pose a risk to accessing project finance and impact hydropower's reputation.

The authors found that reducing GHG emissions at hydropower dams requires multiple enabling factors, most notably through financial incentives, legislation, regulations, and more accurate GHG measuring. There is consensus within the hydropower community that to deliver meaningful emissions reductions, the responsibility lies across the stakeholder value chain, requiring the cooperation of financial institutions, industry bodies and hydropower owners and operators.

The introduction of additional financial incentives and regulations is likely to lead to increased GHG emissions auditing and encourage the development of technologies at hydropower dams to reduce these emissions. Some technologies will continue to focus on reducing the production of methane from within the reservoirs. However, for reservoirs where preventing all methane production is not cost-effective or possible, the industry may look to methane capture technologies as a possible alternative to reduce GHG emissions and where the intrinsic value of methane as an energy source can be utilised.

Given the increased awareness of GHG emissions and the efforts to monitor and mitigate them in other industries, the authors are optimistic that there is a case for methane capture from hydropower dams. ◊

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L. Parlons Bentata is Co-founder and CEO of Bluemethane. She has deep expertise in brand strategy, marketing, sustainability and innovation. As a consultant prior to Bluemethane, Louise supported management teams in global and SME companies with marketing, strategy, branding and lead generation, and has experience across all major regions. Her client experience focused on specialist engineering and manufacturing industries. Louise holds an MBA from INSEAD, an MA in Geography from Cambridge University and a postgraduate Certificate in Sustainable Business from Cambridge University.


L. Parlons Bentata

N. Rueda Vallejo is Co-founder and CTO of Bluemethane. He specialises in structural integrity and process optimisation using computational modelling and simulation tools. Néstor's focus has been on the development of engineering projects under the most challenging environments and situations for hydropower, public utilities, process, and mining companies across Europe and Latin America. Néstor holds a BSc and a MSc in Mechanical Engineering.


N. Rueda Vallejo

Bluemethane, 20-22 Shelton Street, London, WC2H 9JJ, UK.