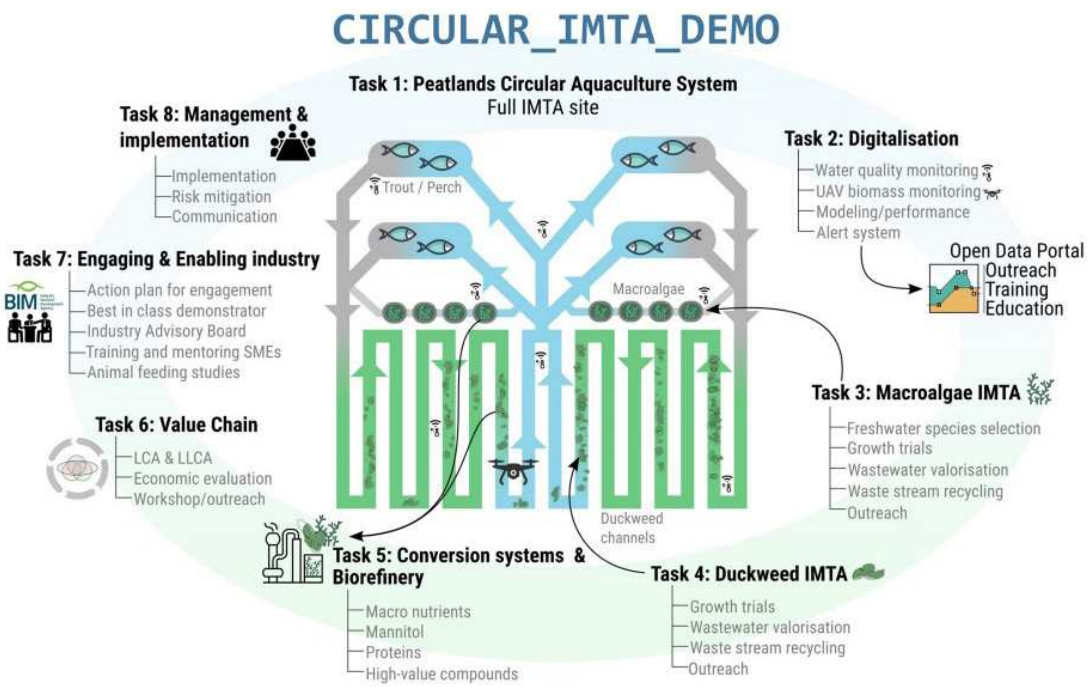
# REWETTED PEATLANDS FOR CO-CREATING RECIRCULATING AQUACULTURE AND FOR DRIVING AQUATECH – QUO VADIS?

*Neil J Rowan*

***An innovative and award-winning recirculating multi-trophic aquaculture (IMTA) site in the peatlands of the Irish midlands demonstrates how aquaculture can be tailored to meet food security needs while achieving several circular bioeconomy goals such as low cost, zero-waste, zero-pollution, and production of new value-added products from the generated biomass. Equally important is the fact that it offers easy access to technological support for business entrepreneurs, policymakers and other multi-actors in the interest of a cleaner and resource-efficient world.***




*Credit: Technological University of the Shannon (TUS), Ireland*

There is growing interest in supporting and growing aquaculture and related aquatech that provides safe nutritious food supply and contributes to global food security by meeting the increasing diverse needs of our growing populations [1]. This is particularly relevant given that captured fisheries are now at their maximum sustainable yields [2]. These important aquaculture activities enable the co-creation of new innovation and products that drive resilience and regional regeneration, leading to employment, security and economic prosperity.

The ambition to grow aquaculture is framed and tailored into strategic policies that reflect national goals for economic growth, balanced with environmental compliance. Meeting complex societal demands in a blue economy that embraces multi-actor needs is a complex process [3, 4]; and where there is pressure on fragile resources, including managing environmental pollution. The Food and Agriculture Organization of the United Nations (FAO) estimates 35% growth in aquaculture production by 2030 where it is projected to produce substantially more than captured fisheries by some 6 million tonnes [5]. Indeed, there is an increasing interest in exploiting low-cost environmental-friendly "natural" processes in aquaculture [6]. Next-generation farming is clearly where investor confidence lies, as attested by USD 295 million (48% of total investment) in 2024. Nutrition solutions followed at USD 144 million with regenerative farming securing USD 48 million. Interestingly, RAS sector growth appears remarkable where producers experienced funding more than double year-over-year reaching USD 250 million in 2024.

In a recent networking event held in Athlone (Ireland) by Bord Iascaigh Mhara (Ireland's Seafood Development Agency), emerging trends to drive key technology investment in aquaculture were presented by Hatch Blue that included (i) health and welfare improvements through diagnostic tools, feed additives and genetics; (ii) digitalisation and automation of farm data, water management and feeding systems; (iii) alternative ingredients exploration for more sustainable feed sources; and (iv) new farming systems, including intensification, offshore and underwater solutions. Thus, the availability of appropriate pilot and commercial demonstration at scale to help aquaculture will provide opportunities for co-creation and to de-risk for investment in innovation that includes meeting balanced environmental needs and concerns.

There is an emerging opportunity to avail of the rewetted peatlands to grow aquaculture internationally [7], which also enables communities to pivot away from reliance on using fossil fuels. Peatlands, which cover about 3% of our planet's land surface [8], are water-saturated ecosystems of decomposing organic material referred to as "peat" [9]. Peatlands constitute the world's largest terrestrial carbon stock, storing approximately 5 050 gigatonnes of carbon that is greater than the total carbon stored in forests globally [8]. Moreover, there is a growing opportunity to develop appropriate and effective recirculating aquaculture processes using rewetted peatlands that do not discharge effluent to the receiving environment [10]. A monitored and defined aquaculture system in the peatlands can be potentially operated to zero-waste, zero-pollution and climate action principles, as well as meeting food security needs [10].

One such example is an integrated multi-trophic aquaculture (IMTA) process, which is a type of aquaculture where the byproducts, including waste, from one aquatic species are used as inputs (such as fertilisers, food) for another. Farmers combine fed aquaculture (e.g., fish, shrimp) with inorganic extractive (e.g., seaweed) and organic extractive (e.g., shellfish) aquaculture to create balanced systems for environment remediation (biomitigation), economic stability (improved output, lower cost, product diversification and risk reduction) and social acceptability (better management practices) [1, 10].

## Peatlands-based IMTA project in Ireland

Approximately 17% of the land surface within Ireland is covered by peatlands [10]. Since 2020 there has been a shift towards rewetting bogs (peatlands) as important carbon sinks along with supporting alternative eco-friendly innovation [11, 13]. The commensurate use of multi-actor demonstration sites offers potential bridging solution(s) to supporting companies and entrepreneurs as this potentially addresses co-creation, end-to-end testing, scalability, risk mitigation and commercialisation of new innovation at scale [13]. An IMTA demonstration site in the Irish midlands at Mount Lucas wind farm, Co. Offaly, Ireland (53◦17'3'' N - 7◦11'45'' W) represents a novel peatlands-based aquaculture approach that has an underpinning circular bioeconomy functionality. It also offers an exciting opportunity to demonstrate aquaculture/aquatech at scale where these combined topics constitute one of the fastest food-producing industries in the world [1, 10] (Figure 1). An aerial image of the IMTA site is shown in Figure 2.


*Figure 1. Yellow box indicates geographic location of IMTA peatlands site in the Irish midlands.*

*Figure 2. Aerial drone image of peatland IMTA site in the Irish midlands.*

This reflects pressing needs arising from an ever-growing global population where farmed fish is accepted to be a highly efficient protein source of nutritional food [14]. Moreover, aquaculture provides food security and improved nutrition including for territories and countries that would have limited fisheries [15]. Hatch Blue noted that future investments in the nutrition innovation space intimated insect-based feed (USD 68 million) and single-cell protein (USD 44 million) as emerging sustainable solutions. The role of aquaculture in driving new innovation is attested by the World Food Prize for transformative fish feed products and by specific project funding under Ireland's Disruptive Technology Innovation Fund.

## IMTA site demonstrates possibilities

The IMTA peatland system does not use chemical biocides and consists of four split (pill) ponds for culturing rainbow trout *(Oncorhynchus myriis)* connected to an algae and duckweed lagoon with sixteen channels serving as a natural treatment system (Figure 3). The recirculatory site is 5.4 hectares in size where flow in each split pond is generated and water is circulated using an airlift. Each D-end fish culture area is equipped with oxygen and temperature probes connected to paddlewheels to provide extra oxygen when necessary. Power is supplied by an onsite wind turbine. The farm is designed to hold a maximum of 32 000 kg of fish [10].

*Figure 3. Rainbow trout produced at the Irish IMTA site*

The IMTA model will operate as a circular bioeconomy commercial demonstration site where microalgae and duckweed (Figure 4) biomass use nitrogen and phosphorus from fish culture (faeces) in waste stream channels to return clean water to the D-end pill ponds (schematically represented in Figure 2). Paolacci and co-workers [26], who assessed the water quality of this IMTA system pre- and post-treatment with duckweed, showed that the system can remove 0.78 and 0.38 tonnes per year of Total Nitrogen and Total Phosphorus respectively. This shows that duckweed can maintain good water quality in the IMTA system, while yielding high protein content (21.84 ±2.45%) biomass for potential animal or human feed applications. The fish waste stream will also be used for production of onsite freshwater macroalgae in land-based tanks.

*Figure 4. Duckweed produced at the IMTA site that can be biorefined and fed to fish.*

This IMTA system markedly differs from other traditional aquaculture systems that use water from natural sources (such as rivers and lakes), which must consider pollutants from external sources (such as wastewater treatment plants, agricultural run-off and so forth) [15]. Developments onsite include the addition of an innovation suite for networking and training end-users; a living laboratory that includes an extended reality suite; and a biorefinery for biomaterial extraction such as from naturally-occurring duckweed and microalgae, along with the tank-based macroalgae that will also serve to inform new feed potential while supplementing the cost of maintaining large stocks of fish in the D-ponds.

Interestingly, this IMTA framework also addresses the innovation gaps identified by Aidoo and Kwofie [16] for meeting their proposed conceptual "circular bioeconomy accounting tool", which recognises the importance of fostering harmony between participating stakeholders and developing an appropriate integrative sustainability assessment relevant to solution design and performance monitoring. The Irish IMTA site considers use of public-private partnerships and change of land use under a fair and just transition for communities, farmers and other end-users[1].

## Discussion

In essence, IMTA is a state-of-the-art approach that integrates different species from various trophic levels in a single aquaculture system [15]. In the case of the Irish Mount Lucas IMTA approach, this involves fish and photosynthetic organisms like microalgae and aquatic plants, where their natural relationships enhance efficiency and reuse of waste streams, producing biomass from cascades [1]. This creates a circular bioeconomy demonstration environment yielding new value-added products from the generated biomass [1, 15]. The overarching "circular" reuse approach involves nutrient recycling where fish pond waste (excreted faeces) rich in nitrogen and phosphate become a resource for lower trophic primary producing species in the ponds and channels, thus reducing nutrient loads and mitigating the occurrence of euthrophication [1]. Essentially, this establishes a defined naturally-balanced synergistic ecosystem fostering nutrient flows and inter-species relationships that negate environmental impact, improve water quality and biomass yield. Nutrient flow can also be used for onsite production of freshwater macroalgae and possibly future aquaponic applications.

Optimising this IMTA peatland approach demands strategic design and effective management, including spatial arrangement for waste to disperse towards algal and aquatic plant (duckweed) growth areas, promoting interspecies relationships throughout the entire site [10]. Spatial design also involves the strategic placing of species in proximity to each other, such as filter feeders adjacent to fish to use waste nutrients. The roles of subject-matter experts on site is crucial, such as environmental (civil) wastewater engineers; this ensures effective managing of water and waste flow for facilitating nutrient exchange and maintaining optimised growth conditions for all trophic species. This includes creating the best conditions for natural filtration capabilities of certain trophic species. Moreover, the site should exhibit stable hydrology, appropriate pH levels, and minimal pollution to support these diverse aquaculture species.

This IMTA process will contribute to restoring degraded peatlands into their natural state, thus facilitating carbon sequestration and an ecological balance that also mitigates against the use of unwanted chemicals [15]. Other successful examples of IMTA systems have been reported globally, such as fish farming in combination with reed bed filtration systems in the United Kingdom [17]; integrating shrimp farming with mangrove restoration in Indonesia that reduces erosion and augments carbon sequestration [18]; and combining salmon farming with seaweed and mussel cultivation in Canada's Atlantic region [19] to improve nutrient recycling and environmental impact.

The Irish government has taken steps towards turning Ireland into a global bioeconomy leader, promoting access to Mount Lucas as a national demonstration site for aquaculture and aquatech with a linked bioeconomy theme [1]. The strategic policies in Ireland that have global relevance include boosting employment and new business opportunities in rural, regional, urban, and coastal areas through innovation products, services and technologies; increasing food and energy security; supporting climate action by displacing fossil fuels; promoting a circular economy and reducing waste; providing high-value diversification opportunities for transforming agrifood systems; and leveraging research, development and innovation capabilities to address bioeconomy, societal and environmental challenges [20]. The pivotal role of integrated demonstration facilities in developing tangible bio-based opportunities at scale (including digital transformation) has yet be described [16, 21].

Defining a circular IMTA in the peatlands for production of trout, microalgae and macroalgae biomass provides an excellent example of a tangible "in action model" that can be replicated globally [15]. The mortality on site in the production of trout in Irish peatlands is very low [1]; however, the site is exposed to the elements where it has experienced significant challenges in managing the effects of successive storms and variance in weathering. Thus, this site also enabled modelling and prediction as to the impact of changing weather events and patterns on open food ecosystems, to both understand and mitigate against the impact of climate change [15].

The IMTA site will be connected fully to digital sensors to facilitate the optimal reuse of waste and sludge. In addition, there will be an onsite extended reality suite that enables 360° visualisation of the site operation, including the remote development of bespoke aquatech innovation. Such a defined IMTA system is in sync with the environment where profiling of different tropic levels enables eco-labelling (green) for new products that are compliant with ecology and with nature. The IMTA site at Mount Lucas does not rely on the use of pesticides or antibiotics, nor the complex use of physical technologies for end-of-pipe solutions for treating effluent. Developing such IMTA sites in the peatlands creates new exciting opportunities in terms of usage, while educating our next generation of change-makers for a cleaner resource-efficient world.

## Summary

Despite the growth and interest in aquaculture globally, there remains few published studies on the combined use and involvement of key multi-actors to effectively interpret strategic policies from a bottom-up user perspective [22]. Essentially, coordinating the co-development of regional, national and international aquaculture processes requires the alignment of overarching ambitions with matched consensus on key performance indicators as these will provide evidence-based data to help inform repeatability and quantifiable impact. Open access and use of shared facilities at the Mount Lucas IMTA site also support entrepreneurs and companies to test their aquatech and to de-risk for investment using a "go, no go" approach [1]. The ecosystem of enablers on site will provide advice to companies, start-ups and entrepreneurs on the viability of business cases and potential risks for an end-to-end life-cycle-assessment (LCA) perspective.

The IMTA site, operated through a subject matter expert approach in aquaculture, also facilitates tailored support and messaging to end-users for bespoke needs. This includes digital transformation and the emergence of artificial intelligence and machine learning for new innovation [23, 24, 25]. The remoteness and complexity of this peatlands IMTA site offers enormous potential for discovery of new species of microalgae due to its exposure and tolerance of harsh environments [10] that can lead to the biorefinery and production of novel new products. The site operates at the interface between serving innovator/entrepreneur demonstrator needs and interpreting/informing top-down strategic policies for food production and security that will also help sustainable development, given current economic and geopolitical turmoil.

For example, use of next-generation sequencing and bioinformatics of pond samples revealed a combined total of 982 species from 341 genera across nine phyla [10]. This is a remarkable and exciting commercial screening opportunity (such as for cosmetic, pharma and biotech applications), given that use of conventional microscopy revealed only 20 or so different species. Duckweed that is produced based on use of waste stream and cascades in IMTA channels can be harvested and biorefined on site, where it comprises about 30% protein available for animal or human feed [1]. The aforementioned highlights the opportunities for co-creation and innovation using a defined freshwater aquaculture site where new species within an IMTA ecosystem can also potentially be discovered depending on future geographic locations of peatland rewetting and replication of process. The nexus to supporting education and training programmes, including for communities interested in upskilling and in social enterprises, is apparent and transformative.

In summary, the co-creation of such a peatlands-IMTA site enables new innovation to be developed and tested in a defined ecosystem that also accelerates the need to understand and address key pressures, including meeting biodiversity along with demonstrating at scale for viable business propositions. This holistic IMTA site also enables development of aquaculture that will help policymakers understand and tailor strategic policies relevant to regions and bespoke needs. Such a defined system that embraces open data-sharing will enable replication in other geographic regions; however, considerations such as use of native species of duckweed, fish species and ecology will need to be carefully considered. Furthermore, the integration of education enables and supports longevity as it provides a framework to create an ecosystem of a new highly trained workforce equipped with cross-disciplinary skills.

## References

1. Rowan N.J., Fort A, O'Neill EA, Clifford E, Jansen M, Helfert M, Toner D, Maguire J, Tiwari B. (2024) Development of a novel recirculatory multitrophic peatland system for the production of high-value bio-based products at scale embracing zero waste and pollution principles to unlock sustainable development goals. Case Studies in Chemical and Environmental Engineering Jun;9:100763. Available from: https://linkinghub.elsevier.com/retrieve/pii/S2666016424001579

2. Tschirner, M., Kloas,W. (2017) Increasing the Sustainability of Aquaculture Systems: Insects as Alternative Protein Source for Fish Diets. Ecological Perspectives for Science and Society, Vol 26 (4), 332-340.

3. Faulkner, J.P., Murphy, E., Scott, M. (2024). Downscaling EU bioeconomy policy for national implementation. Cleaner and Circular Bioeconomy, Vol. 9, https://doi.org/10.1016/j.clcb.2024.100121

4. Richter, S., Szarka, N., Beama, A., Thran, D. (2025). Enhancing the circular bioeconomy transition in Germany: A systematic scenario analysis. Sustainable Production and Consumption. 53, 125-146.

5. ResearchandMarkets (2023) https://www.globenewswire.com/news-release/2024/08/23/2934836/28124/en/Aquaculture-Global-Strategic-Business-Report-2023-2030-Developing-World-Adopts-Aquaculture-to-Ward-off-Malnutrition-Presents-Significant-Growth-Opportunities.html (accessed 11th March, 2025)

6. Yue, K., Shen, Y. (2022). An overview of disruptive technologies for aquaculture. Aquaculture and Fisheries, Vol 7 (2), 111-120.

7. O'Neill, E.A., Stejskal, V., Paolacci, S., Jansen, M.A.K. and Rowan, N.J. (2024). Quo vadis - Development of a novel peatland-based recirculating aquaculture multi-trophic pond system (RAMPS) in the Irish midlands with a global orientation. Case Studies in Chemical and Environmental Engineering, 9, https://doi.org/10.1016/j.cscee.2024.100748

8. IUCN UK (2024) About peatlands. https://www.iucn-uk-peatlandprogramme.org/about-peatlands#:~:text=Peatlands%20cover%203%25%20of%20the,in%20all%20the%20world's%20forests. (accessed 15 Feb, 2025)

9. Tanneberger, F., Appulo, L., Ewert, S., Lakner, S., Ó Brolcháin, N., Peters, J. and Wichtmann, W., 2021. The power of nature-based solutions: how peatlands can help us to achieve key EU sustainability objectives. Advanced Sustainable Systems, 5(1), p.2000146.

10. O'Neill, E.A., Fehrenbach, G., Murphy, E., Alencar, S.A., Pogue, R. and Rowan, N.J. (2022b). Use of next generation sequencing and bioinformatics for profiling freshwater eukaryotic microalgae in a novel peatland integrated multi-trophic aquaculture (IMTA) system: Case study from the Republic of Ireland. Science of the Total Environment, 851 (2), https://doi.org/10.1016/j.scitotenv.2022.158392

11. Galanakis, C.M., Rizou, M., Aldawoud, T.M.S., Ucak. I. and Rowan, N.J. (2021). Innovations and technology disruptions in the food sector within the COVID-19 pandemic and post-lockdown era. Trends in Food Science and Technology, 110, 193

12. Bord Na Mona Accelerate Green (2024). An executive accelerator designed to scale your sustainability-driven business.https://accelerategreen.ie (accessed 16th Feb, 2025)

13. Huguenin, A., Jaennarat, H. (2017). Creating change through pilot and demonstration projects: Towards a valuation policy approach. Research Policy, Vol 46 (3), 624-635

14. Nissar S, Bakhtiyar Y, Arafat MY, Andrabi S, Mir ZA, Khan NA, Langer S. The evolution of integrated multi-trophic aquaculture in context of its design and components paving way to valorization via optimization and diversification. Aquaculture [Internet]. 2023 Feb;565:739074. Available from: https://linkinghub.elsevier.com/retrieve/pii/S0044848622011917

15. O'Neill, E.A., Stejskal, V., Paolacci, S., Jansen, M.A.K. and Rowan, N.J. (2024). Quo vadis - Development of a novel peatland-based recirculating aquaculture multi-trophic pond system (RAMPS) in the Irish midlands with a global orientation. Case Studies in Chemical and Environmental Engineering, 9, https://doi.org/10.1016/j.cscee.2024.100748

16. Aidoo, R., Kwofie, E.M. (2024). Circular bioeconomy account tools (CBEAT): A holistic framework for agriculture and agri-food system circularity practice. Sustain Sci. https://doi.org/1007/ss11625-024-01578-3

17. Fletcher, S., Saunders, J., Herbert, R., Roberts, C., Dawson, K. (2012). Description of the Ecosystem Services Provided by Broad-Scale Habitats and Features of Conservation importance: They are likely to be protected by Marine Protected areas in the Marine Conservation Zone Project area. Natural England Commissioned Reports, Number 088, York, England.

18. Sakinah, L. (2024), Putting Indonesia's aquaculture sector on the map. The fish site. https://thefishsite.com/articles/putting-indonesia-aquaculture-sector-on-the-map-ita-sualia (accessed 21 January, 2025).

19. Van Beijnen, J., Yan, G. (2024). The multi-tropic revolution: A deep dive with IMTA Guru Thierry Chopin. The fish site. https://thefishsite.com/articles/the-multi-trophic-revolution-a-deep-dive-with-imta-guru-thierry-chopin-polyculture-salmon-mussels-seaweed (accessed 21 December, 2025)

20. International Advisory Council on Global Bioeconomy (2024). Bioeconomy globalization: recent trends and drivers of national programs and policies. https://www.iacgb.net/lw_resource/datapool/systemfiles/elements/files/52440fb0-f35d-11ee-9ed1-dead53a91d31/current/document/Global_Bioeconomy_-_April_2024_IACGB.pdf (accessed 13 Dec, 2024)

21. McBride, O. (2024). Shared Island Bioeconomy Demonstration Initiative Launched. The Fishing Daily. https://thefishingdaily.com/latest-news/shared-island-bioeconomy-demonstration-initiative-launched/ (accessed 15 December, 2024)

22. Rowan, N.J. and Casey, O. (2021). 'Empower Eco' multi-actor HUB: A triple helix 'academia-industry-authority' approach to creating and sharing potentially disruptive tools for addressing novel and emerging new Green Deal opportunities under a United Nations Sustainable Development Goals framework. Current Opinion in Environmental Science and Health, 21, https://doi.org/10.1016/j.coesh.2021.100254

23. Rowan, N.J., Murray, N., Qiao, Y., O'Neill, E., Clifford, E., Barcelo, D. and Power, D.M. (2022). Digital transformation of peatland eco-innovations ('Paludiculture'): Enabling a paradigm shift towards the real-time sustainable production of 'green-friendly' products and services. Science of the Total Environment, 838 (3), https://doi.org/10.1016/j.scitotenv.2022.156328

24. Rowan, N.J. (2023). The role of digital technologies in supporting and improving fishery and aquaculture across the supply chain – Quo Vadis? Aquaculture and Fisheries, 8 (4), 365-374.

25. Rowan, N.J. (2024). Digital technologies to unlock safe and sustainable opportunities for medical device and healthcare sectors with a focus on the combined use of digital twin and extended reality applications: A review. Science of the Total Environment, Vol 926, https://doi.org/10.1016/j.scitotenv.2024.171672

26. Paolacci, S., Stejskal, V., Toner, D., Jansen, M.A.K. (2022). Wastewater valorisation in an integrated multitrophic aquaculture system: Assessing nutrient removal and biomass production by duckweed species. Environmental Pollution, Vol. 302, https://doi.org/10.1016/j.envpol.2022.119059


*__Dr Neil Rowan__ is Professor of Applied Microbiology and Biotechnology at Technological University of the Shannon (TUS) in Ireland. He has conducted research in food systems and innovation for over 30 years including developing aquaculture. He has supervised 42 PhDs to completion in this, and related areas that encompass approximately 300 journal and conference papers. He is recognised as a top performing researcher globally for these disciplines including appearing in the 2024 Standford University list. Prof Rowan is lead PI for developing an IMTA bioeconomy demonstration project in Ireland and acknowledges DAFM, EU Just Transition Fund and Bord Iascaigh Mhara for funding.*