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Current Opinion in
Environmental Science & Health

Empower Eco multiactor 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

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Abstract

There is a pressing drive to address climate change and environmental degradation that are global existential threats. Europe has strategically responded by unifying efforts to transform its connected communities into a modern, resource-efficient and competitive economy with a trajectory to enable net nil greenhouse gas emissions by 2050; thus, ensuring economic growth is decoupled from resource utilisation, and that no person or place is left behind. The European Green Deal is an ambitious plan to make the European economy sustainable; however, there is no reference blue-print for the safe and just transitioning to a low carbon economy. This constitutes the first description of a triple helix (academic-industry-authority) concept underpinning operation of multiactor innovation hub that can be strategically applied to enable this transition that develops green innovation and enterprises. Innovative tools for meeting the United Nations' Sustainable Development Goals are informed by appropriate technology, policy and society readiness levels from idea to final market/wider society deployment. "Empower-Eco Sustainability HUB," is a digitised "living lab" established in the Irish peatlands that converges academia, communities, social enterprises, industries, policy and decision-makers. It develops green innovation in intended environments at demo/test-beds, such as for digital, agri-food, bioeconomy and bio-based sectors, and embraces climate-proofing and COVID-19 recovery.

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Current Opinion in Environmental Science & Health 2021, **21:**100254

This reviews comes from a themed issue on **Environmental Toxicology 2021: Disruptive Green Deal Innovations**

Edited by **Neil J. Rowan** and **Robert Pogue**

For a complete overview see the Issue and the Editorial

https://doi.org/10.1016/j.coesh.2021.100254

Keywords

Just transition, New Green Deal, Sustainability, Open research, Multi-actor hub, Circularity, UN Sustainable Development Goals.

Introduction

Climate change and environmental degradation are recognised as existential threats that require urgent transnational action [1–3]. Ebi et al. [2] also stated that human health and wellbeing and the health of the biosphere are inextricably linked. Ebi et al. identified four main themes: (1) risk identification and management (including related to water, hygiene, sanitation and waste management); food production and consumption; oceans; and extreme weather events and climate change. (2) strengthening climate-resilient health systems; (3) monitoring, surveillance and evaluation; and (4) risk communication. They reported that research needs to be "transdisciplinary, multi-scalar, inclusive, equitable and broadly communicated; thus, promoting resilient and sustainable development are critical for achieving human and planetary health". The European Green Deal is an ambitious plan to make the European economy sustainable, which will inform a panoply of new policies, programmes and legislation that will propel Europe's Green Deal, Biodiversity, Farm to Fork and Circular Economy plans [4,5]; this is set against a backdrop of economic recovery, including changes to trade agreements due to BREXIT and ongoing COVID-19 pandemic [6].

Addressing pressing climate and environmental challenges will potentially create opportunities leading to sustaining or potentially new disruptive solutions [7]. For example, there is a pressing need to develop breakthrough 'circularity' solutions to replace the current 'take-make-dispose' economy that will positively have an impact on food waste regeneration, resource utilisation and climate change [8]. Adopting nonconventional approaches to research will avoid untapped outcomes that typically can occur in silos associated with traditional research, which limit their use and benefit to stakeholders. Unlocking the value of impact from research innovation in these areas remains a significant challenge due to *inter alia* barriers, lack of trust between different actors, perceptions of the social consequences to change, economic barriers to investment, and unclear returns [9]. Gaining an appreciation of the effective use, re-use and upcycle loops will inform next-generation eco-solutions that that will meet research gaps of enterprises along with tailoring education and training [1,10]. Recovering from the ongoing COVID-19 pandemic will create opportunities directly influencing our environment, our health and our society [11]. There is also a growing interest in supporting "One Health" as a global concept that recognises that humans, animals and their shared environments are interconnected. It is increasingly apparent that it is necessary to take a One Health approach to tackle many of the health challenges we face in today's world with nexus to environmental protection, resource utilisation and sustainablity.

Developing and exploiting multiactor HUB approaches to unlock eco-innovation for new Green Deal era – lessons learnt from transnational modelling

One approach is to developing multiactor eco-innovation hubs that will drive open responsible research and innovation, such as in the areas of smart agri-food, forestry, marine, and bio-based systems [8,12]. Such a surge in interest will be informed by the outputs of transnational models and clusters that focus on drivers for change [1,13]. Multiactor HUBs will enable future solutions to improve waste mitigation and improve food security are likely to embrace open sharing of knowledge intra-regionally that can stimulate regeneration; this will be informed by life cycle assessment such as unlocking the nexus between food, energy and water to inform enterprise [14,15]. Eco-hubs will enable a structured 'holistic systems' approach that cuts across sectors and disciplines and engages multiple actors to deliver co-benefits for health, sustainability, climate and inclusion [1,12]. This is similar to the "triple-helix" concept of converging academia, industry and authorities to address complex challenges and to unlock green opportunities. For example, a circular food and resource supply can potentially become a reality where wasteful practices can stop, and circularity can be designed into all new products and services from the start [8]; however, for this to occur, a disruptive approach to channel effort will be required, including step changes in education that informs environmental literacy and behavioural change. Transnational modelling of technology core facilities and clusters for regional development, such as that described by European Interreg projects [1,13], have highlighted the need to develop multiactor hubs that link academia with industry and stakeholders. These create opportunities for sharing infrastructure and skills that underpin the needs of SMEs linked to academia that potentially lead to advances in sustaining and new disruptive technologies [7,16,17]. Loorbach et al. [18] also conceptualised that the development of such transformative initiatives can occur through growing, replicating, partnering, instrumentalising and embedding; this is supported through translocal networks that connect initiatives by sharing ideas, objects and activities across local contexts. This need also extends to econometric models for assessing government policies to support SMEs in the context of meeting ongoing and future pandemics [19]. However, there has been a significant interest in advancing supply chain disruption and risk mitigation to manage COVID-19 and to support recovery, including improving the networking of multiactors and beneficiaries [20]. Development of Green innovation from idea to market introduction, along with wider societal deployment, will also be informed technology, policy and societal readiness levels that are increasingly being used by research funding bodies [9] (Table 1).

Emerging opportunities using the peatlands

The peatlands account for ca. 3% of the earth's surface and as an important CO_2 sink where it stores approximately 1.4 trillion tonnes of carbon that is equivalent to 75% of carbon in our atmosphere [1]. Several European-funded Interreg projects, such as NWE Carbon Connects [21], North Sea CANAPE [22], NWE Care Peat [23]), have focused on restoring peatlands and biodiversity, sequestering carbon and supporting wet-peatland innovation. 'Paludiculture' crops described in the aforementioned include sphagnum moss, moor-grasses, wild rice, typha and so forth. These transnational projects, along with EC's "*Platform for Coal Regions in Transition*" initiative, support transitioning away from exploiting fossil fuels to develop more climate-resilient solutions [1,24]. Paludiculture focused-activities could be extended to supporting enterprise and research in designated 'green development zones', such as for eco-design, testing and eco-labelling of new environmental-friendly products and services [25]. For example, Bord Na Mona, a State Body that manages 80,000 ha of 'organic status' peatland in the Republic of Ireland, has aggressively adopted such a new '*Brown to Green Strategy*' that also includes controlled re-wetting of the peatlands for conservation along with forging climate solutions based on sustainable resource utilisation and green innovation. Consequently, many workers require re-training/upskilling in these areas. It is noteworthy that the global Green Technology and Sustainability market size is to potentially grow from USD 11.2 billion in 2020 to USD 36.6 billion by 2025, at a Compound Annual Growth Rate (CAGR) of 26.6% during the forecast period [26]; these include targeted technologies (such as IoT, AI and analytics, digital twin, cloud computing), and applications (such green building, carbon footprint management, weather monitoring and forecasting).

Table 1

Applying triple helix of technology, policy and society readiness levels to inform the development of a green project, a technology, a product, a process, a management practice, an intervention or an innovation from initial idea to market launch, scheme and wider societal development.

Technology Readiness Levels[a] (TRL)[a]		Policy Readiness Levels[b] (PRL)		Society Readiness Levels[c] (SFL)	
TRL 1 – Basic Research – Principles postulated and observed –no experimental proof (Discovery)	Knowledge development Academia	**PRL 1 –Basic Research** – identifying issue/problem and identifying policy readiness (Discovery)	Knowledge development Academia	**SRL 1 – Basic Research** – identifying a problem and identifying societal readiness (Discovery)	Knowledge development Academia
TRL 2 – Technology Concept Formulated – concept and application defined (Concept Definition)		**PRL 2 – Formulation** of issue/problem, proposed solutions and potential impact; expected policy readiness; concept identification relevant to stakeholders (Concept Definition)		**SRL 2 – Formulation** of problem, proposed solution(s) and potential impact, expected societal readiness; identifying intended stakeholders for project (Concept Definition)	
TRL 3 –Experimental Applied Research Concept – first laboratory tests completed (Proof of Concept)		**PRL 3 – First testing** of proposed solution(s) with relevant stakeholders; modelling, consultations, feedback, development complete (Proof of Concept).		**SRL 3 – Applied Research** - initial testing of proposed solution(s) with intended stakeholders (Proof of Concept)	
TRL 4 – Technology Validated in Lab – Small scale prototype – built and tested in lab (lab validation)		**PRL 4 – Problem validated 'in lab'** through pilot testing in intended environment to substantiate proposed impact, policy readiness, feedback development (lab validation)		**SRL 4 – Pilot-Test Scale** - concept validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness (Concept Validation)	
TRL 5 Large-Scale Prototype tested in intended environment (test facility validation	Technology development Collaboration	**PRL 5 – Proposed solution(s) validated**; now by intended stakeholders in the area for application ('open water' validation)	Policy Development Collaboration	**SRL 5 – Large Scale Test/system -** proposed solution(s) validated; with intended stakeholders ('open water' validation)	Solution Development Collaboration
TRL 6 – Technology demonstrated in intended environment – close to expected performance ('open water' validation)		**PRL 6 – Demonstration system** in intended environment and with intended stakeholders at pre-role out scale for feedback on impact (system demo)		**SRL 6 – Demonstrated system** - solution(s) demonstrated in relevant environment and with intended stakeholders for feedback on policy	
TRL 7 – System prototype demonstration in operational environment – at pre-commercial scale (system demo)		**PRL 7 – System refinement** of scheme and/or solution(s), and possibly, retesting in intended environment with intended stakeholders to gain feedback (refinement)		**SRL 7 – System Refinement** – refinement of product, and/or solution(s), and if needed, retesting in intended environment with stakeholders (refinement)	
TRL 8 – First system complete, qualified, verified – First commercial system – manufactured issues solved (verification)	Business development Industry	**PTL 8 – First System** - proposed solution(s), as well as plan for policy **adaptation complete, and qualified** (verification)	Scheme development Government	**SRL 8 – First System** – issues solved, proposed solution(s), as well as plan for societal adaption complete, and qualified (verification)	Stakeholder development/ Society
TRL 9 – Actual Full commercial system proven in operational environment – technology available for beneficiaries (deployment)		**PRL 9 – Policy Implementation** – actual project solution(s) proven in relevant environment. Issues solved, continued monitoring, evaluation, and review of scheme/solution (deployment)		**SRL 9 – Full Social System** – actual project solution(s) in intended or relevant environment (deployment)	

[a] TRL – are indicators of status or maturity level of particular technology been researched and commonly used for European Commission in the context of Horizon Europe. Adapted from [9].

[b] PRL – Used to assess the level of societal adaptation to project, technology, product, process or management practice, or innovation to be integrated into policy. Adapted from [9].

[c] SRL – Used to assess the level of societal adaptation to project, technology, product, process or management practice, or innovation to be integrated into society. Adapted from [9].

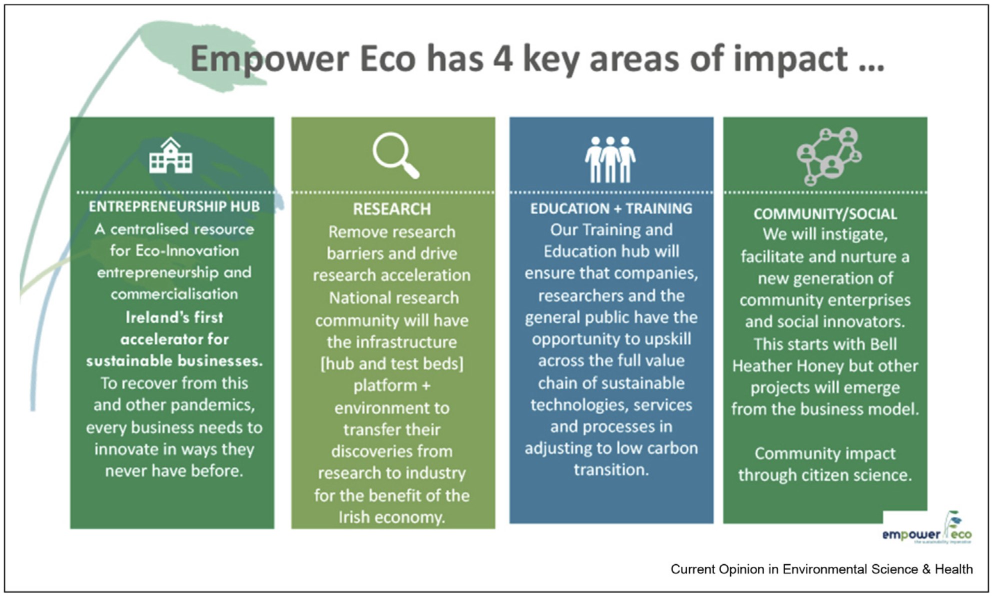
Figure 1

Empower Eco Sustainability HUB" supporting a dynamic converging community and enterprise ecosystem for transitioning to the new Green Deal era; this fosters a triple-helix concept (academia-industry-authority) to enabling and accelerating change to green innovation in the Irish midlands.

Empower Eco – Irish midlands multiactor platform to support and accelerate a just transition to low carbon economy

Empower Eco constitutes the first new Green Deal "multiactor hub" accelerator that supports and connects research, innovation, social enterprises along with enabling community transitioning to low carbon economy through engagement with broad stakeholder from a bottom-up perspective (Figure 1). It constitutes a signature multifunctional digitised building at Boora, in the heart of the Irish peatland that connects research, entrepreneurship, enterprise and the community (Figure 2). While the focus of Empower Eco is geared to support and enable other green-innovative projects funded under Just Transition [24], it is specifically developing environmental testbed activities that include the use of 6 ha of freshwater aquaculture and aeroponics, 34 ha of horticulture comprising 12 different medicinal plants and herbs, 5 ha of agroforestry. Social enterprises include deploying 200 new hives across the peatlands to promote pollination and ecosystem service management, where 'Bell Heather' honey is produced at the regional Ferbane Food Hub (Figure 1). Activities conducted across Empower Eco ecosystem meet EC Green Deal ambitions [27], including (a) supporting, investing, testing environmentally-friendly technologies

Figure 2



Empower Eco Sustainability HUB has four inter-related foundation pillars connecting entrepreneurship, research, education and training, community and social activities that will guide just transition to low carbon economy in Irish midlands with a national and international orientation.

across agri-food, horticulture, agroforestry, vertical-farming, biofuels, circular economy and digitisation; (b) supporting industry to innovate, (c) decarbonising the energy sector – specifically expanding biofuel and wind energy initiatives, (d) ensuring that buildings are more energy-efficient and (e) working with international partners to provide global environmental standards and international mobility for SME training. Herrero et al. [16] also recently highlighted the potential for such innovation to accelerate the transition to sustainable food systems. Empower Eco can also escalate this approach by way of addressing eco-design and eco-labelling that focuses on green products ranging from concept to testing at pilot scale linked to LCA [25]; this also embraces carbon emissions and energy measurements using these peatland testbeds [21–23]. In addition, this provides useful testbed data for impact climate monitoring and forecasting.

The 'living lab' concept connects the need for real-time sophisticated analysis HUB infrastructure, such as using molecular profiling (such as MinION genomic sequencing) and bioreactors for mass-balance simulated studies to inform testing and validation of in-field monitoring devices at the testbeds [28]. Early needs analysis for market research, product-market fit analysis and design for scale–up processes are addressed that includes (1) early pilot and technical validation, including 'test the tech' (beta testing/field testing); (2) experimentation and validation at prepilot scale in real-life environments, (3) providing a commercial platform, and commercialisation vehicle for research for SMEs, and emanating from connected 3rd level institutions; and (4) embracing ICT, digitisation and exploit immersive technologies for linked research, innovation and training. Empower Eco activities strongly align across several policy areas, including biodiversity (measures to protect our fragile ecosystem); from farm to fork (ways to ensure more sustainable food systems); sustainable agriculture (sustainability in agriculture and rural needs informed by common agricultural policy (CAP)); clean energy (wind and biofuels); sustainable industry (ways to ensure more sustainable, more environmentally respectful production cycles); green building and renovating; eliminating pollution (measures to cut and monitor pollution rapidly and efficiently); climate action (making Ireland and the EU climate neutral by 2050, including creating monitoring of innovation and testbeds) [9].

Empower Eco will evaluate fundamental data trends, scenario modelling, mitigation measures, risk analysis in order to implement future policies that will strengthen the environmental sustainability and competitiveness of Irish and European partnering food industries. Empower Eco will address the development of data-driven and natural capital approaches to inform bio-resources, businesses, services and value chains, which includes promoting new partnerships and innovation ecosystems between producers, processors, retailers and society. Examples of how this triple helix approach can be used as sustaining or potential disruptive green innovation for addressing United Nation's Sustainable Development Goals of this approach was also applied to

Table 2

Empower Eco activities and tools to support, enable and accelerate potential green innovation disruption under United Nations' Sustainable Development Goals (SDGS) framework.

UN Sustainable Development Goal[a]	Indicative sustaining or potentially disruptive activity under linked Empower Eco triple-helix management platform
No poverty	Food security, food systems, and sustainability along with digitisation via open knowledge and technology sharing with developing countries. Researcher mobility and exchanges creating opportunities in education.
Zero hunger	Development and future proofing sustainable agri–food processes and crops along with alternative sources for protein that includes training.
Good health and wellbeing	Adopting One Health approach to informing green innovation – there is a strong focus on community transition and social enterprise for health – this includes food for good approach that includes provision for research and innovation to pivot beyond COVID-19 [33].
Quality Education	Sharing knowledge, discoveries and growing collaborations in academia, ex-Delta Africa and Irish Research Council Coalesce Programme. Appointing Visiting Research Fellows from Developing Countries to Empower Eco projects for the dual translation of know-how that includes food for good, health and wellbeing that cross-cuts STEM with Social Science and humanities, to inform behavioural change.
Gender Equality	Empower Eco projects are strong gender equality focused with equal representation in research, innovation and entrepreneurship across projects, tasks, management that includes Project Advisory Team.
Clean Water and Sanitation	Innovative green research and enterprise to promote natural resources for water quality and mitigate waste that moves beyond end-of-pipe solutions [1,38].
Affordable and Clean Energy	Empower Eco enables and accelerates green innovations by developing affordable and clean energy that includes "Hub and spoke model" to testing and verifying technologies in intended environments using LCA, modelling and by applying technology, policy and society readiness levels [Table 1]. Carbon sink measurements on peatlands with nexus to specialist training [50,52]. Recirculating aquaculture system with 'organic status' in Irish peatlands is driven by wind turbines [1,38].
Decent work and Economic Growth	Empower Eco adopts a triple helix approach (academia-industry-authority) to inform techno-social-economic feasibility and impact that is framed upon pivoting activities to hurdle regional, national and international challenges (including COVID-19) informed by econometric and transnational modelling of key clusters for sustainable change.
Industry, Innovation, Infrastructure	Empower Eco framework, or connected ecosystem, has assembled appropriate mix of academia, industries, and enterprises to accelerate green innovation that includes sharing and access to specialist infrastructure, equipment and resources where focus is on regional transition to low carbon economy and impact. With nexus to Education
Reduced Inequalities	Empower Eco triple helix management team approach that ensures education and research for all as its' core underpinning tenet.
Sustainable Cities and Communities	Empower Eco is focused on community transitioning to low carbon economy where there was a strong reliance on fossil fuels – community groups are strongly represented in management group and Empower Eco has registered as a 'Company with Limited Guarantee' to support not-for-profit and charitable activities to support its communities.
Responsible Consumption and Production	Responsible consumption and production are core activities of Empower Eco in terms of research and enterprise – Empower Eco also develops digital twin, factory of the future, industry 4.0 concepts.
Climate Action	Empower Eco addresses climate action by developing more sustainable green innovation that are climate proofed – this includes biosensor technology for monitoring more resilient innovation [36] – this is informed by networking with international partners such as EC Horizon 2020 and Interreg programmes that includes data from transnational models. Demo and test-beds in relevant and intended environments will render big data for climate impact modelling.
Life Below Water	Empower Eco is supporting freshwater aquaculture and studies on biodiversity related to natural aquatic ecosystems in peatlands
Life On Land	Empower Eco is supporting studies on biodiversity, pollination and ecosystem service management that includes studies on key drivers affecting decline of animal pollinators (bees) [3,35]. This is co-funded by the Environmental Protection Agency.

Table 2 (*continued*)

UN Sustainable Development Goal[a]	Indicative sustaining or potentially disruptive activity under linked Empower Eco triple-helix management platform
Peace, Justice and Strong Institutions	Peace, justice and strong institutions are key founding tenets of Empower Eco that blends academia, industry, authority with communities.
Partnerships for the goals	Empower Eco supports and enable national and international partnerships aligned with UN SDGs that includes mobility and training.

[a] Alignment with https://www.un.org/sustainabledevelopment/sustainable-development-goals/.

describing potential sustaining or disruptive tools for meeting needs of the United Nations Sustainable Development Goals Framework are provided in (Table 2).

Bio-based and bio-inspired smart functional products from the peatlands

Due to its harsh and stressed environment [29], the peatlands of Europe provide a rich resource for refining new bio-inspired materials with improved functionality and sustainability for potential health and wellbeing applications, such as high value nutraceuticals, cosmetics and personal care products. This includes the development of novel bioactive compounds or ingredients for promoting health and wellbeing in humans and animals [30–33], along with testing and developing potentially disruptive green technologies [16,28,34,35]. Opportunities for harvesting immune-priming bioactives from food waste streams for potentially addressing the surge in antimicrobial resistance (AMR) that contributes to pulmonary sepsis and pneumonia should be pursued through a One Health approach [31,32]. Data-driven development solutions to optimise biomass availability and to inform the development of robust supply chains, business cases, including potential social enterprise models for sustainable and circular bio-based value chains, will be advanced [9].

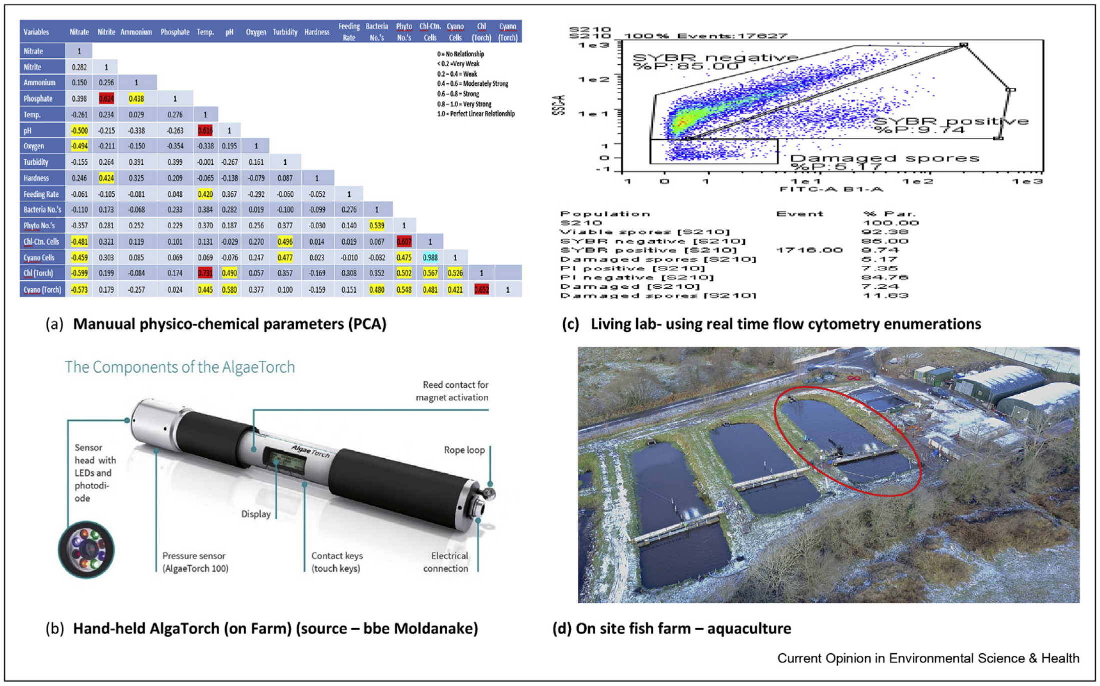
Example of sustainable innovation using “Empower Eco” HUB: freshwater aquaculture

Aquaculture is the fastest growing food production section in the world [36]. It has an average annual growth rate of 6–8% since 2000 [36] that has been positively influenced by smart fishing and the increase in the seafood and aquaculture trade. Negative connotations associated with farmed seafood, such as pollution, poor animal welfare, nonsustainable depletion of resources, disease spreading and drug use, erodes the social license to produce [37]. Freshwater aquaculture in the Irish peatlands is framed upon using naturally occurring microalgae, bacteria and duckweed in the ponds as a means of water quality and waste recycling, where trout and perch are farmed based upon organic principles and use wind turbines [38]. The process is defined to optimise ‘circularity’ knowledge and to mitigate waste. This sustainable system moves away from end-of-pipe effluent treatment to embrace a full recirculation system; however, unexpected operational challenges have been experienced due to large rainfalls associated with multiple storms in 2020 that caused a ‘flux’ in the system, causing fish fatalities. This testbed also has exploited innovative environmentally friendly diagnostic and monitoring technologies, along with connected real-time determination potential of living labs (using real-time ‘in lab’ evaluation) with on-site handheld microalgae torch to monitor production processes [Figure 3]. This system will be digitised to inform the full process, validation and management decision tools that include the use of machine learning along with the potential for virtual Quality of Experience training [39]. Table 3 highlights the potential for future-proofing the aquaculture industry using green innovation developed through this triple-helix management approach.

COVID-19 response and sustainability

There are increasing waves of SARS-CoV-2 infection globally that include more transmissible and pathogenic variants that exert enhanced pressure on personal and protective equipment (PPE) supply chains globally [40]. PPE shortages, such as filtering facepiece respirators or medical face masks, have been met by increased manufacture, by emergency use authorisation of nonthermal reprocessing technologies (such as VH2O2, UV) for PPE reuse and digitisation of the supply chain [41]. PPE is an important nonpharmaceutical intervention strategy that reduces the relative risk of SARS-CoV-2 infection and will continue to accompany vaccination for mitigating this COVID-19 disease and future pandemics. PPE that has single use-plastic items has generated a new waste management challenge where there are opportunities for using sustainable bio-inspired alternatives to that of using plastic constituents. These alternative bio-based solutions are to be potentially met from natural material such as food waste stream, bioplastic upcycling, and so forth [8]. For example, these biomaterials could be introduced by electrospinning to improve filtration efficacy below 300 nm cut pore size in face masks (where SARS-CoV-2 is typically 60–140 nm in size) [42,43]; however, other functional parameters must be met by original equipment manufacturers, namely pressure

Figure 3



Variables	Nitrate	Nitrite	Ammonium	Phosphate	Temp.	pH	Oxygen	Turbidity	Hardness	Feeding Rate	Bacteria No.'s	Phyto No.'s	Chl-Ctn. Cells	Cyano Cells	Chl (Torch)	Cyano (Torch)
Nitrate	1															
Nitrite	0.282	1														
Ammonium	0.150	0.296	1													
Phosphate	0.398	0.624	0.438	1												
Temp.	-0.261	0.234	0.029	0.276	1											
pH	-0.500	-0.215	-0.338	-0.263	0.616	1										
Oxygen	-0.494	-0.211	-0.150	-0.354	-0.338	0.195	1									
Turbidity	-0.155	0.264	0.391	0.399	-0.001	-0.267	0.161	1								
Hardness	0.246	0.424	0.325	0.209	-0.065	-0.138	-0.079	0.087	1							
Feeding Rate	-0.061	-0.105	-0.081	0.048	0.420	0.367	-0.292	-0.060	-0.052	1						
Bacteria No.'s	-0.110	0.173	-0.068	0.233	0.384	0.282	0.019	-0.100	-0.099	0.276	1					
Phyto No.'s	-0.357	0.281	0.252	0.229	0.370	0.187	0.256	0.377	-0.030	0.140	0.539	1				
Chl-Ctn. Cells	-0.481	0.321	0.119	0.101	0.131	-0.029	0.270	0.496	0.014	0.019	0.067	0.607	1			
Cyano Cells	-0.459	0.303	0.085	0.069	0.069	-0.076	0.247	0.477	0.023	-0.010	-0.032	0.475	0.988	1		
Chl (Torch)	-0.599	0.199	-0.084	0.174	0.731	0.490	0.057	0.357	-0.169	0.308	0.352	0.502	0.567	0.526	1	
Cyano (Torch)	-0.573	0.179	-0.257	0.024	0.445	0.580	0.377	0.100	-0.159	0.151	0.480	0.548	0.481	0.421	0.652	1

Pressing need for end-to-end digital monitoring of big data and machine learning that connects **(a)** manual physiochemical parameters and **(b)** hand-help on-farm monitoring with **(c)** with real-time living lab analysis for **(d)** sustainable freshwater aquaculture using IMTA approach.

drop and comfort fit post nonthermal reprocessing to appropriate standards. The peatlands potentially provide a resource of alternative bioplastics to inform new PPE design and functionality for ongoing and future pandemics.

Community-focused transitioning – pressure points and challenges to overcome

Transnational modelling, and regional observational studies have highlighted key drivers to improve the transition of communities and enterprises to low carbon economies [44, 45]. These include:

Building resilient enterprises through

(a) extended supports, such as EI supports, learning from BREXIT/COVID-19 pandemic, transition vouchers; (b) SME digitisation, such as boosting awareness and take-up, simplify appreciation for innovation supports, (c) Enterprise-led networks, such as funding, lessons learned from existing clustering projects, (d) Early-movers, such as if and how to support initiatives.

Continuous pre-emptive workforce development through

(a) increased ambition, such as improved resources, higher targets, incentivise employers; (b) improve information, such as more skills audits, recognised informed skills and information sharking, (c) life-long learning, such as greater effort linked to academic institutions, and (d) better advice, such as pre-unemployment, more one-to-one coaching.

Delivering high-impact targeted funded through

(a) targeted support, including social enterprises and new business/community level engagements and mechanisms, (b) improve support, such as seed funding applications, fund local plan development, and more place-based schemes, and (c) better engagement, such as working with multiactor institutions and monitoring EU developments.

Invest and enable green enterprises and innovation

There is a need to develop and invest in enterprises informed by expert training and research, including pilot testbeds that will accelerate new products and services and dissolve technical barriers [44,46–49]. Emerging business models to roadmap initiatives supporting this include (a) transnational business modelling tailored for circularity – such as developing further successful transnational econometric and cluster models [19,47]; (b) "Invest and enable for accelerating green innovations"; (c) Enterprise HPSU Green SPRINT Programme; (d) support from local enterprise office, local government, community groups, a policy such as Just

Table 3

Climate proofing sustainable freshwater aquaculture using Irish peatlands.

Challenge Area	Detail	Technical, Commercial, Social Resolution
Environment: Climate Change	Internationally, climate change can interact with fisheries in many different ways; a decline in the industry has been attributed in part to increased water temperatures, extreme water flow events (floods and droughts), and warming of maritime and freshwater environments [14,15,47].	Harvesting the potential for peatlands to help with new innovation to transition economy beyond same [38] and designing systems for recirculating avoiding end-of-pipe treatment options [1,28]. Using big data and digitisation from aquaculture testbeds to inform climate impact modelling along with biosensors that detect real-time variations in the aquatic environment due to extreme weather events [28,36].
Environment: Waste Streams and food waste redcuction	Negative connotations associated with farmed seafood, such as pollution, poor animal welfare, nonsustainable depletion of resources, disease spreading and drug use have affected the development of aquaculture. Land-based fish farms require monitoring and treatment to ensure effluent containing nutrients and other physicochemical properties meet discharge to receiving water licence. Failure to achieve this can contribute to problematic algae blooms and fish death.	There has been an enhanced focus on valorising wastes from food production from farm to fork. For example, in the aquaculture industry, solid waste from finfish production has been identified as a potential substrate for anaerobic digestion with a secondary use as a fertiliser. However, there is a pressing need to leverage emerging 'natural 'processes to reduce operational cost and the environmental burden of food production for sustainability of the aquaculture sector. This presents opportunities for green innovation that will be informed by monitoring [37], Life Cycle Assessment, Risk modelling and cos-benefit analysis [15] and novel processes [16,34]
	Chemicals, such as antibiotics, used in the aquaculture industry, can be released into waterways. Future opportunities for Aquaculture systems to be closed or wastewater treated prior to discharge.	Extraction of bioactives, or bioinspired materials with increased functionality from aquaculture waste streams (including from microalgae) that can be used in feed ingredients to promote immune health of farmed fish, thus limiting or avoiding the use of antibiotics [32,33,51].
Disease	Aquaculture operations can spread parasites and disease into the wild. Farmed fish have an increased chance of getting parasites such as sea lice, as opposed to fish that live and breed in their natural environments. Farmed fish are exposed to diseases through the use of unprocessed fish as a food source.	Introduce precision farming techniques that monitor and control disease and prevent infection. Utilise nutritional technologies to maintain the optimum health of the farm. Investigate symbiotic feeding systems that are biodiverse and sustainable. Opportunities for reviewing green innovations from a holistic technology, policy and societal readiness from initial idea to market or system deployment [Table 2].
Cost	Treatments lead to higher costs and lower profitability	Build upon the potential demonstrated in the first radically-new concept in integrated-multitrophic aquaculture (IMTA) that uses cutaway peatland (bogs) to farm fish with an associated organic status that is powered by wind energy and utilises bacteria, microalgae, duckweed to treat rearing water. Developing IMTA systems, along with eco-innovation and monitoring/management processes, is critical for transforming the sector [38]. Use of triple-helix (academic-industry-authority) to inform new innovation linked to stakeholders and beneficiaries that also includes social change.
Future need for food security, and disruptive innovation surrounding supply chain and resource utilisation	The sustained expansion of aquaculture has arisen due to the increasing global population and commensurate demand for more food. Aquaculture now accounts for ca 50% of fishery products, which is estimated to reach ca. 62% by 2030 [37]. However, issues associated with the aquaculture licensing process and the potential environmental impact caused by aquaculture effluent have hampered the expansion of the Irish Aquaculture Industry [1].	
Feed	The feed-protein crisis has exposed the feed industry to shortages in quality protein and the need to import nonsustainably produced soy from places such as the amazon, and/or use wild-caught fish to grow fish.	Plant proteins constitute a novel avenue that has not been adequately explored in Ireland. The development of vertical farming to promote and develop high protein foods and feeds will also advance this area. It is envisaged that Irish aquaculture-farmed perch and trout benefit

(*continued on next page*)

Table 3. (*continued*)

Challenge Area	Detail	Technical, Commercial, Social Resolution
		from consuming duckweed, which along with algae and bacteria, naturally control water quality and waste [1].
Land Impact	Maintaining biodiversity, along with ensuring compliance with policies and statutory regulations, is important when considering developing and deploying land-based facilities. Aquaculture businesses locate near coastlines for easy access to clean and natural water.	Utilising bogs that support natural ecosystems. This also enables the transition from burning peat to lower carbon emissions [1]. Approx. 5% of Ireland is comprised of peat bogs, comprising potential aquaculture and other green enterprises. This will also support the community transitioning to a low carbon Bioeconomy.
COVID-19 crisis and recession	Presents uncertainly and considerable challenges and opportunities for food sustainability and security	Potential for peatlands to help with new innovation to transition economy beyond same, including agri-food and bio-based sectors informing by training [32,50,52].

Transition [24]; (e) entrepreneurship — such as Irelands New Frontiers delivered by Enterprise Ireland; mobility and specialist training for SMEs such as offered through the Hatch Blue Aquaculture Accelerator programme [50] and by National Digital Research Centre (NDRC) for accelerating start-up companies [52]. The aforementioned will also be informed by enabling innovation management through ISO 56000 series that will advance enterprises and grow capability in the green technology and service space.

Conclusions

There is a pressing need to support communities in transitioning to low carbon economies where there is an underpinning drive to empower behavioural change to meet ambitious climate and environmental challenges through creative opportunities. Empower Eco is a multitiered ecosystem approach established to support and accelerate this just transition in the Irish midland peatlands that paradoxically supported rural communities through the burning of peat or supply to products to horticulture. The controlled wetting of the peatlands presents an essential carbon sink for Ireland to meet its net zero GHS emission targets for 2050; however, this also presents considerable innovative opportunities to create social enterprises and to support businesses in forging new green innovations to help with this community transitioning and to increase employment. While lessons have been learnt from outputs of transnational sustainability modelling, life cycle assessment and cost-benefit analysis; Empower Eco constitutes the first multiactor connected ecosystem of stakeholders, spanning academia, industry, authority and communities, for informing a unified transition to low carbon economy using the Irish midland peatlands as a targeted region for regeneration. Unknowns yet to be discerned include elucidating the key drivers that inform sustainable behavioural change of citizens to low carbon economy. Also, the financial stimulus to support for enabling and accelerating green industry and businesses need to be ambitious and flexible to fast tract needs; these should also be linked to academia that can share technological core facilities and provide specialist training. For the impact of climate variance on emerging new sustainable activities, such as farm to fork, an example is the fully recirculated freshwater aquaculture process. Future studies will evaluate critically large-scale meta-data generated from these ambitious multiactor projects that will exploit advances in transnational and risk modelling, life cycle assessment and social marketing framed upon open sharing and access of knowledge. Therefore, Empower Eco describes a tool by which key green innovation and knowledge can be openly and directly transferred to decision makers and shared with stakeholders and beneficiaries. This triple-helix management approach also describes potential disruptive solutions that will inform green innovations such as required under the UN Sustainable Development Goals (SDG) framework.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors wish to acknowledge funding from Just Transition Fund (Project No. MRTT 112_2021); Regional University Network - European Universities (Project No. 101004068) and Interreg Atlantic Area Neptunus (Project No. EAPA_576/2018).

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