Extended Abstract

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Paper/Poster Title	**Modelling the economic performance of recirculating aquaculture systems (RAS) at the farm level**

Abstract prepared for presentation at the 97th Annual Conference of the Agricultural Economics Society, The University of Warwick, United Kingdom

27th – 29th March 2023

Abstract	***200 words max***
Contemporary agricultural production practices are one of the most significant drivers of biodiversity loss and make farming a major contributor to greenhouse gas (GHG) emissions and water pollution. Currently, agricultural policies and farm management interventions at a farm level are designed to contribute to a transformational reform of agricultural systems to improve environmental and economic sustainability. The new Agriculture Act for the UK commits to net zero carbon emissions and policies to enhance environmental stewardship and sustainability and support the production of public goods. Introducing recirculating aquaculture systems with farm-based renewable energy (Anaerobic Digestors, AD) will provide a novel diversified enterprise for farming systems with considerable but poorly understood economic and environmental benefits. Thus, it is necessary to demonstrate the socio-economic impact of a world-leading 'terrestrial blue economy', contributing multiple public goods to reform UK agriculture by combining high-value shrimp ("king prawn") aquaculture and renewable sources of energy at a farm level. The results will provide a high-resolution model of where shrimp farming is most likely to be adopted. Moreover, the outcomes will indicate how each variable affects costs, revenue, output, and profitability of shrimp production relative to other farm activities, hence determining uptake.	

Keywords	Farm profitability, diversification, sustainability, land use, public goods
JEL Code	Q12, Q15, Q16, Q18, Q20, Q22, Q42 see: www.aeaweb.org/jel/guide/jel.php?class=Q)

Introduction	***100 – 250 words***
The derived pressures from the internal (limited natural resources, land degradation) and external environment (agricultural policies, exchange rate, trade agreements) of farming systems allow farmers to introduce innovative and alternative food production technologies. Notably concerning how production systems can be transformed to reduce negative externalities, change land use patterns, and release natural resources (land, water) to provide other land-based services. Furthermore, new food technologies and innovation systems can support the diversification of farm profitability leading to its financial sustainability. Suppose these new enterprises at the farm level have the potential to address the demand for sustainable diets. In that case, such products may provide nutritious substitutes for animal-sourced foods. At the same time, it simultaneously reduces the environmental pressures generated by	

livestock systems and supports the provision of ecosystem services from the agricultural sector. The integration of terrestrial warm-water shrimp ("King prawn") production using recirculating aquaculture systems (RAS) using green energies such as AD has the potential to provide a novel diversified farming output. Furthermore, it can ensure a healthier and sustainable supply chain of this heart - and brain-healthy seafood for UK consumers by facilitating a major expansion of the UK's shrimp RAS production sector which currently supplies equivalent to <1% of imports.

Methodology	***100 – 250 words***

The primary objective is to test the economic viability of RAS & AD in the context of different farm systems in the UK. The modelling design is adjusted to agricultural systems to explore the impact of RAS & AD on farm profitability. During the modelling exercise for the different farm types and the different scales of RAS, all costs (variable and fixed), including capital costs, are considered. To achieve these objectives, a linear programming optimisation technique is used. The method employs a mathematical algorithm based on Jones and Salter (2013)[a], to identify the optimum mix of factors (inputs, resource use, etc.) for the maximisation of farm Net Margin, subject to given constraints (land availability, labour, and capital). The model developed here will contribute to the assessment of the economic viability of terrestrial shrimp production in the UK and to quantify and economically value the public goods generated by this transformation. The outcomes will be used for developing a high-resolution model of where shrimp farming is most likely to be adopted in the UK as the technology develops and as prices, costs, subsidies, and environmental conditions (including climate change) vary. The structural, technology and economic data on which the farm-type models were constructed were derived from multiple sources, including the DEFRA Farm Business Survey (FBS), published farm management standards, literature review (of RAS and AD modelling projects etc), as well as direct from farm-based operators of RAS and AD, their advisers, and suppliers.

[a] Jones, P and A. Salter. 2013. Modelling the economics of farm-based anaerobic digestion in a UK whole-farm context. *Energy Policy* 62, 215-225

Results	***100 – 250 words***

Preliminary analysis show that the majority of AD waste heat is produced by combined Heat & Power (CHP) engines (typically 250-500 kW, which can be adopted at farm level) generating up to 300-600 kW of waste heat (assuming adjustments between summer and winter months), enough to freely heat 6 to 12 tropical shrimp units from 15 to 25 °C. This equates, conservatively, to 34-69 tonnes of shrimp p.a. This shrimp production positively impacts farm profits. Additionally, there are cost savings for farmers since shrimp waste and AD residuals can be used as soil amendments and fertilizer cost savings for shrimp producers. In this regard, we analyse RAS & AD enterprises at different scales to select the best contributors to the farm Net Margin and other indicators. In this regard, if just 120 farms adopt the RAS & AD enterprise for shrimp farming, assuming 8 shrimp units per CHP at the

farm level, we could sustain 960 shrimp production units and harvest 5,520 tonnes of shrimp p.a. This represents 25% of current UK warm-water shrimp imports. It has been rapid AD growth in the UK (10-fold since 2010), in-farm and off-farm, then there is potential for truly sustainable, healthier, future UK-grown shrimp to provide the majority consumed.

Discussion and Conclusion	***100 – 250 words***
Although the positive impact on profits by integrating shrimp production in a terrestrial setting has been demonstrated, it is necessary to incorporate and discuss the spatial variations among production systems in the UK. Thus, assess issues such as changes in regional transport costs, input requirements and market price variation. Bringing terrestrial farm and shrimp models together within a spatially explicit framework will allow the identification of which farms should/shouldn't undertake shrimp production, and where, why, and what happens to other activities and land use. Moreover, explore this spatial linkage to ecosystem service consequences of this uptake and understands how the Public Money for Public Goods (PMPG) principle within the Agriculture Act affects this result by establishing the impacts of different, spatially targeted, subsidy schemes and rates of support upon uptake of shrimp production on UK farms. To further enhance the current work, the economic modelling will need to be combined with a modelling of the supply of ecosystem services and enhancement of biodiversity. Thus, produce a spatially explicit economic model that links the spatial distribution and structure of land use to biophysical and chemical processes that constrain the delivery of ecosystem services and thus reveal the potential or not of establishing terrestrial shrimp production systems.	