Harper Adams University

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Proceedings of the 7th Symposium on Agri-Tech Economics for Sustainable Futures

28 – 29th September 2024, Reading, United Kingdom

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Proceedings of the 7th Symposium on Agri-Tech Economics for Sustainable Futures

Global Institute for Agri-Tech Economics (GIATE)
Harper Adams Business School
Harper Adams University
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All times are for the United Kingdom (BST / UTC+1)

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Session Chair: Dimitrios Paparas & Karl Behrendt (Harper Adams University), Yiorgos Gadanakis (University of Reading)	
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Rebecca Payne (Head of Harper Adams Business School, HAU)	Welcome, Harper Adams University directions and thank you.
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Dr. Shampa Roy-Mukherjee, University of East London	Keynote: The Agenda for Change in Business Education to Address the Key Dimensions of Sustainability: Society, Environment and Economy.

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Keynote: Challenges, opportunities and resilience: towards an agenda for Agri-tech economics

Professor Janet Dwyer

University of Gloucestershire, The Park, Cheltenham, UK

Presenter Profile

Professor Janet Dwyer directs and undertakes applied research related to agriculture, the environment and rural development. Her research expertise centres on the evaluation and development of European and UK rural development policy and practice, with particular interest in integrated approaches, environmental sustainability and institutional adaptation.

Prof Dwyer is well-known in policymaking circles in the UK and EU, has skills in facilitation and consensus-building, and is a regular speaker at international conferences. Her work has influenced the development and design of agri-environmental and rural policies in the UK, Ireland and Malta, and at the European level within the European Commission's DGs for Agriculture and rural development, Environment, and Climate.

Prof Dwyer sits on a variety of NGO and government-sponsored policy advisory groups in England including Green Alliance, the RSA's Food, Farming and Countryside Commission and Defra's Rural Academic Panel, and chaired Defra's Nutrient Management Expert Group, 2021-22. Janet is a Director of Rural England CIC, and a Trustee of the Organic Research Centre and the Countryside and Community Foundation. She is a former President of the Agricultural Economics Society, a Fellow of the Royal Agricultural Societies and a Membre Associé of the French Academie d'Agriculture. She was awarded an OBE in the June 2022 Queen's birthday honours for her services to rural research.

Keynote: The Agenda for Change in Business Education to Address the Key Dimensions of Sustainability: Society, Environment and Economy

Dr Shampa Roy-Mukherjee

Royal Docks School of Business & Law, University of East London, London, UK.

Presenter Profile

Shampa is Vice Dean and a Professor of Economics at the Royal Docks School of Business and Law, at the University of East London who over the past decade, has demonstrated sustained and impactful leadership, working closely with the Executive Dean to shape and implement the School's strategic priorities. Her work directly contributes to the University's Vision 2028 strategic objectives, with a focus on fostering a Connected Campus, advancing the 5.0 Economy, and promoting Equality, Diversity, and Inclusion. Her research is internationally recognized, with a strong publication record in Political Economy, Applied Econometrics, Socio-Economic and Health Inequalities, the Gig Economy, and Financial Development and Growth. As the Co-Director of two research centres - The Noon Centre for Equality and Diversity and The Centre for the Study of States, Markets, and People (STAMP), She leads interdisciplinary and collaborative research projects that enhance the University's research profile and global visibility.

Beyond her work at the university, Shampa is actively involved in external partnerships with universities, businesses, and communities, both locally and globally. These collaborations are crucial to advancing the University's Vision 2028 goals and expanding impact. She also contributes to the broader academic community as a member of the editorial boards for the Journal of Balkan and Near Eastern Studies and The Journal of Global Faultlines, where she helps shape scholarly discourse in her field. In recognition of her contributions, Shampa has been awarded the title of Guangdong Distinguished Overseas Professor at Guangdong University of Finance & Economics in China and has served as a Visiting Scholar at University Jaume I Castellón in Spain.

Shampa's career is marked by a commitment to academic excellence, impactful research, and strategic leadership, all of which contribute to the University of East London's mission and its global standing.

Keynote: Accelerating innovation in the agricultural sector: challenges and opportunities

Dr Phil Bicknell

UK Agri-Tech Centre, Innovation Centre York Science Park, Heslington, York, UK

Presenter Profile

Phil Bicknell was appointed CEO of the UK Agri-Tech Centre as it launched in April 2024. He joined CIEL - one of the three companies which merged to create the UK Agri-Tech Centre - in 2021. Prior to the UK Agri-Tech Centre, Phil has had a varied career across food and farming: he led the 50-strong market intelligence team at the Agricultural and Horticultural Development Board (AHDB), equipping farmers and processors with the insight to manage market volatility, profitability and policy change; he was also chief economist at the National Farmers Union (NFU), spearheading the evidence to support a range of lobbying activity. Other roles include specialising in agri-trade issues at the US Department of Agriculture and advising a range of agribusiness clients with Bidwells. Phil grew up on the family livestock farm and has a degree in agricultural economics.

Public Perception of Biodiversity Landscape Elements and Autonomous Technologies in Small-Scale Production Systems

Andreas Gabriel, Johanna Garnitz and Olivia Spykman

Bavarian State Research Center for Agriculture, Germany

Abstract

The perception and evaluation of rural landscapes resulting from human interaction with nature is highly subjective. However, understanding how the non-agricultural population views the impact of an altered landscape image is crucial. This paper explores the German population's perceptions of changes in agricultural landscapes brought about by multi-crop, small-scale field structures (strip intercropping) combined with the introduction of biodiversity landscape elements and field robotics. An online survey was conducted with German residents aged 18 and older (n = 2,022). Preferences and the importance of individual image components were analysed based on four images depicting a field with strip intercropping, featuring various combinations of tractors, robots, and flowering strips. Participants' emotional associations with key image components were also measured. The findings reveal that nearly two-thirds of respondents preferred the image featuring a flower strip and a tractor, associating it with concepts such as green, nature, and environment (flowering strip), as well as the traditional image of agriculture (tractor). Among the two images without flower strips, the tractor was preferred over the robot by more than a sixfold margin. Conversely, the image with a robot and flower strips was chosen about as frequently as the image with a tractor but without flower strips. Additionally, the study highlights how socio-demographic characteristics may influence the evaluation of agricultural landscape changes. Two logistic regression models indicate that factors such as age, gender, direct contact with farmers, and respondents' reported "green consumption value" significantly impact preferences of specific landscape components. Overall, the results suggest a preference for landscapes that are both familiar and environmentally oriented. Nevertheless, the use of autonomous technologies and the shift towards small-scale diversified production systems are not broadly rejected.

Keywords

Autonomous farming technologies; biodiversity; public acceptance; rural landscape; strip intercropping.

Presenter Profile

Andreas Gabriel is a member of the 'Digital Farming' working group at the Bavarian State Research Center for Agriculture. With extensive experience in empirical social research, his work focuses on investigating the social acceptance and adoption of digital technologies in agricultural practice.

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Introduction

The visual perception of a rural landscape ("landscape image") is an important factor for acceptance of individual features in agricultural structures among both agricultural stakeholders and the general public. This perception is influenced, e.g. by associated farming processes and environmental effects and is strongly shaped by the subjective perspective of the individual (cf. Roth et al., 2011). Therefore, interactions such as the introduction of new production systems and structural elements (e.g., agroforestry systems, flower strips, etc.) or the use of new technologies (e.g., field robots) to promote ecological sustainability must also be discussed and evaluated in terms of its impact on the landscape.

In light of current efforts to promote biodiversity-enhancing production systems (FAO, 2023; Ruggeri Laderchi et al., 2024), small-scale diversified crop production systems such as strip intercropping are gaining importance (cf. Alarcón-Segura et al., 2022; Spykman et al., 2023). Strip intercropping refers to the simultaneous cultivation of different crops on the same field in parallel strips (Vandermeer, 1989). If established on a larger scale, this production system has far-reaching impacts on the landscape image compared to conventional farming. It is assumed that the management of such small-scale diversified production systems can be made labour-efficient through automation (e.g., automatic steering systems and section control), or by using autonomous technologies such as field robots or drones (cf. Lowenberg-DeBoer, 2021; Gackstetter et al., 2023). Particularly, the introduction of autonomous technologies would further change both the aesthetic appearance of the landscape and agricultural practices.

Previous research has demonstrated the influence of user experience and knowledge about a technology's purpose on the evaluation of its visual impact on the landscape image: Dentzmann and Goldberger (2020) examined images of a biodegradable alternative to conventional polyethylene mulching foil in focus group discussions with farmers. It was found that the evaluation of this alternative was strongly dependent on the experiences of the respondents, with functional knowledge influencing the visual assessment (Dentzmann and Goldberger, 2020). The visual assessment of the landscape image within the professional group is thus also based on knowledge about farming methods, their feasibility, and economic prospects.

However, it is not easy to determine how groups that are not familiar with the operational functions of landscape-shaping farming measures will react to changes in the landscape. Positive ecological effects often occur as part of conservation measures associated with "disorder", but these measures do not necessarily diminish a certain preference for "tidy" landscapes and familiar landscape images. In this regard, farmers differ from the non-agricultural society in their perception and evaluation of the landscape (Burton, 2012). In contrast to farmers, the non-agricultural society partly evaluates linearity in landscape images as negative and "unnatural" (Laroche et al., 2018). The aesthetic perception weighs heavier than other evaluation criteria such as agricultural production or conservation. It is postulated that planting natural elements (e.g., bushes) in linear, structured cultivation forms (e.g., straight rows) can evoke feelings of "cultural dissonance" (Laroche et al., 2018). However, the type of landscape image culturally established is relevant in this context. For example, an agroforestry system within traditional orchards generates higher acceptance (e.g., measured in higher willingness to pay) if more than one crop is grown between the tree rows (Alcon et al., 2020), i.e., if more structures are present. However, not only the visual quality of the landscape was evaluated, but also the associated ecosystem services and cultural heritage, represented by manual management as opposed to a tractor (Alcon et al., 2020). This approach also points to the complex interplay of visual perception and associated processes for the non-agricultural population. Warren-Kretzschmar and Von Haaren (2014) emphasize the relevance of positive visual evaluation by society as an important aspect besides the ecological benefits of agricultural practice. This likely also generates acceptance for a change in the cultural landscape.

In addition to changes in the landscape image through new agricultural systems or structural elements, an impact from the use of technologies in the fields is expected. Although autonomous technologies such as field robots are associated with various benefits, including reduced labour costs (Lowenberg-DeBoer et al., 2021), a survey of farmers showed that concerns about a negative image of "alienated agriculture" in the population can influence the planned acquisition of field robots (Spykman et al., 2021). Previous research on the population suggests that field robots tend to be rated neutral to positive (Pfeiffer et al., 2020). However, Willmes et al. (2022) describe a negative impact on the willingness to pay for food produced with the help of digital technologies. The authors add that this negative impact can be reduced by additional ecological benefits of the technologies. These findings are reflected in a choice experiment on autonomous technologies in weed control, where the method of weed control (mechanical vs. herbicide broadcast and spot-spraying) influenced the decision more than the degree of autonomy of the technologies used (Spykman et al., 2022). However, a joint consideration of autonomous technologies and altered production systems has not yet been undertaken.

The aim of this paper is to analyse the perception of the German population regarding new small-scale diversified production systems, the integration of structural (biodiversity) elements such as flower strips, and the use of autonomous technologies such as field robots using an online survey. A special focus is on identifying and evaluating the triggers for potential preferences and the connections to individual visual components. This is done by categorizing short associations provided by survey participants in connection with their preference decisions. Furthermore, this paper also includes a segmentation analysis and illustrates how various sociodemographic characteristics of the population influence the evaluation of agricultural elements such as flower strips or the use of automated technologies.

Methods

Online survey among the German population

A nationwide online survey of the German population aged 18 and older was conducted from mid-September to mid-October 2023. Access to this consumer panel was facilitated through the engagement of a field service provider. The use of a consumer panel allows the separation of personal data and content data, so that research ethics can be assured. The panel enables a pre-stratification of the sample to ensure that participants were representative of the German population in terms of age, gender, size of residential area, and federal state. In addition to various sociodemographic data, information on leisure activities in rural areas, personal connections to agriculture, attitudes towards technology, local food production and sustainable consumption, and knowledge of agriculture, was gathered using established market research methods. After the final data validation, the survey sample comprised 2,022 usable and completed data sets.

Analysis of preferences, motives, and short associations

In a question set regarding visual evaluation, participants were asked to assess various aspects of a landscape image with strip intercropping using four photomontages. All four image variants were based on an identical strip intercropping image which shows a machine passage. The differences included the use of a field robot instead of a tractor and the presence of flower strip. All four images were photomontages that were deliberately not realistic (slightly divergent size of the machines) but were designed to increase the recognizability of the various components for participants (Table 1).

Table 1: Choice of image variants for respondents

Variants	Robot/ no flower strip	Tractor/ no flower strip	Robot/ with flower strip	Tractor/ with flower strip
Visualization of the image variants for selection				

Note: Image sources: Photomontages, Bavarian State Research Center for Agriculture, 2023.

The four images were presented simultaneously to the participants and without randomised arrangements. After selecting their preferred image variant, participants were asked to choose three out of six predetermined image components that influenced their decision, ranking them in order of importance. Four of the six selection options were ‘the robot in the field’, ‘the tractor in the field’, ‘the flower strip between the fields’, and ‘the tidiness of the adjacent field strips’ as variable image components. The latter component refers to the order and straightness of the parallel field strips as a structured form of cultivation without any interruption, e.g., by a flower strip. As a control option, participants were offered ‘the beautiful row of trees in the background’, which was identical in all image variants. As the sixth selection option, ‘another reason’ could have been chosen and provided with a text response. The selected image components were counted and weighted according to their specified rank — rank 1 received a triple weight, rank 2 double weights, and rank 3 single weights. This approach allows for the consideration of all three mentioned image components and a composite ranking.

In a follow-up question, survey participants were asked to provide up to three short associations in the form of keywords related to the decisive image component (first rank). These rather spontaneous associations to the picture components shown offer additional insights into the decisive image component and the choice of image variant. While the ranking of predetermined image components served the cognitive evaluation by the participants, the affective and thus emotion-based approach of short associations provides another dimension for determining acceptance (Busch et al., 2019; Pfeiffer et al., 2020; Langer et al., 2022). After data cleaning, a total of 4,872 usable keywords as spontaneous associations for the components of the four images were available. Most of these were related to image 4 (tractor/with flower strip), for which a total of 3,092 keywords were analysed and categorised, manually and in several iterations, into 33 categories. From these, the 16 most frequently mentioned categories (covering 2,995 keywords) were identified and prepared for this contribution.

Modelling the factors influencing preferences

Another goal of this contribution is to identify possible sociodemographic influences on the preference for one of the four image variants. Based on similar studies, it was assumed that personal factors such as age, gender, size of residential area, or living in a specific region (e.g., East Germany with large-structured landscapes) play a role, as may the respondents' direct connection to an agricultural environment (Devlin, 2005; Boogard et al., 2008; Pfeiffer et al., 2020). Additionally, the Green Consumption Value (GCV), which reflects the respondents' tendency towards environmentally friendly shopping behaviour, was used as a value- and attitude-based factor. This was measured using six items (Haws et al., 2014). These six items, presented in a Likert-type scale format, were condensed into an individual standardized factor score through factor analysis and considered as a metric predictor for the selection of the image variant. Since respondents could also choose between the use of a tractor and a field robot in the images shown, the attitude towards technology (ATT) was assessed using nine items in a Likert scale format and condensed into a standardized factor score (Edison and Geissler, 2003). For both scales, negative factor values indicate a stronger manifestation of this characteristic, while positive values indicate a lower manifestation. While the typology of survey participants regarding GCV is right-skewed, indicating that participants' purchasing behaviour is predominantly environmental-conscious according to their statements, attitude towards technology is more evenly distributed, showing a balanced ratio between technology-oriented and tech-averse respondents (Figure 1).

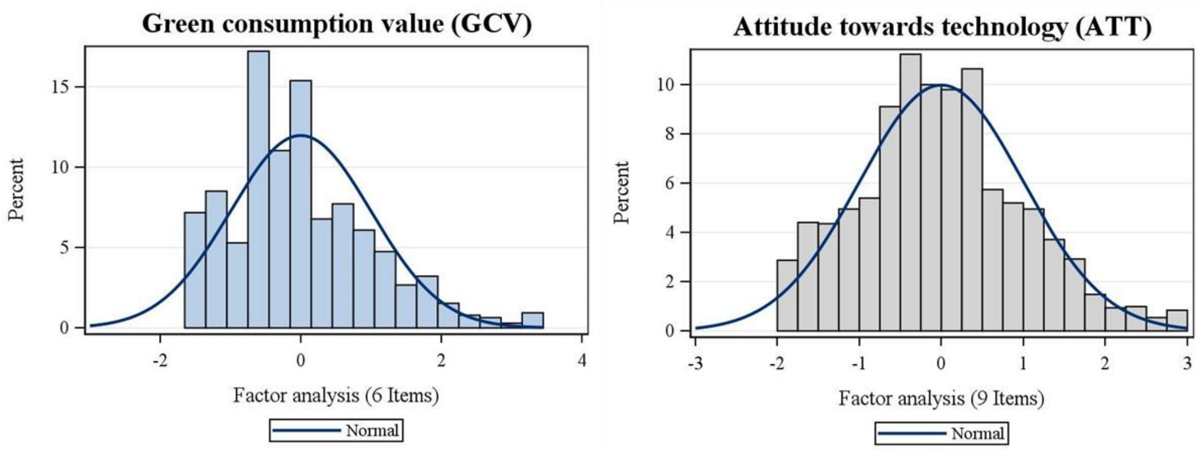

Figure 1: Distribution of the factor values for green consumption value (GCV) and the attitude towards technology (ATT) of the respondents (n = 2,022); GVC: median: -0.11; skewness: 0.774; kurtosis: 0.525; ATT: median: -0.09, skewness: 0.339; kurtosis: -0.127

Multivariate regression models determine the relationships between multiple predictor variables and a dependent variable. For binomial and categorical dependent variables, logistic procedures are used to determine the probability of the occurrence or non-occurrence of an event (e.g., selection of an image) based on the values of the included predictor variables (Backhaus et al., 2018). Logistic regression provides information about the transformation of the dependent variable logit (p):

$$logit(p) = ln\, p/(1-p) \; = \; ln\,(Odds\ Ratio) \qquad (1)$$

where p is the probability that the selection of a particular image is influenced by the measured characteristics, and 1−p is the corresponding non-selection. The odds ratio represents the ratio of these two probabilities. When incorporating k predictor variables, the model takes the following form:

$$logit(p) = \ln p/(1-p) \ = \ \beta_0 \ + \ \beta_1 x_1 \ + \ \beta_2 x_2 \ + \ \ldots \ + \ \beta_k x_k \qquad (2)$$

The regression equation provides information about the importance of each predictor based on the values of the coefficients (βk), allowing for the creation of a hierarchy of the measured variables' effects on group assignment (Backhaus et al., 2018).

To capture the overall effects and explanatory contribution of the selected influencing factors on image preferences based on the specific image elements 'image with robot' and 'image with flower strip', two binomial logistic regression models were estimated. For this purpose, the image preference was dummy coded as the dependent variable (Model A: 1 = one of the two images with a robot was chosen; Model B: 1 = one of the two images with a flower strip was chosen). Sociodemographic characteristics included gender (1 = female), age (1 = < 40 years), size of residential area (1 = < 20,000 inhabitants), geographical location (1 = western German states), and educational level (1 = no general higher education entrance qualification). Respondents' statements regarding personal connection to agriculture was included in the modelling either as personal employment in the sector (1 = yes) or through personal contact with agriculture in the circle of friends or acquaintances (1 = yes) (cf. Pfeiffer et al., 2020). The metric factor scores of GCV and ATT were also integrated into the two models as additional independent characteristics.

Results

Distribution of preferences and selection motives

In a central question, participants were asked to evaluate changes in the landscape based on single images, considering both the use of robots instead of tractors and the additional use of flower strip. The overall distribution of the stated preferences indicates that the variant with flower strip in conjunction with fieldwork performed by tractors is preferred (Image 4 in Table 1: 67.6%). The image variant 'tractor without flower strip' (Image 2 in Table 1) is preferred by 15.3% of the 2,022 respondents, while 14.6% chose the robot in combination with flower strip (Image 3 in Table 1). Only 2.5% of the survey participants favoured image 1 (see Table 1), in which the robot was depicted on the field without flower strip.

Figure 2 shows the results of the ranking of the image components that were decisive for the participants' preference choices. For images 3 and 4, which depict the robot and the tractor respectively, the flower strip shown in both images is the primary component (41% and 43%, respectively).

This is followed by the technical aspect – robot or tractor – with 27% and 28%, respectively. The 'beautiful row of trees in the background', an identical component in all four images, ranks third in both variants (13% and 14%, respectively). The 'tidiness of the adjacent field strips' is also frequently mentioned for both images 3 and 4, with 13% each. For images 1 and 2, which depict the robot or tractor without the flower strip, the focus is primarily on the technological aspect, cited as the reason by 39% for the robot and 40% for the tractor. The second place in these variants is occupied by the 'tidiness of the adjacent field strips' (30% and 31%). As 'other reasons', respondents noted for image 2 (tractor without flower strip) that it best represents the familiar image of traditional agriculture and that the flower strip is perceived as rather disruptive to core fieldwork. Regarding image 4 (tractor with flower strip), some respondents remarked that the flower strip specifically symbolizes nature and animal conservation for them. For images 1 and 3, which show fieldwork done by a robot, innovation, potential efficiency gains, and novelty were mentioned as distinct motives for selection.

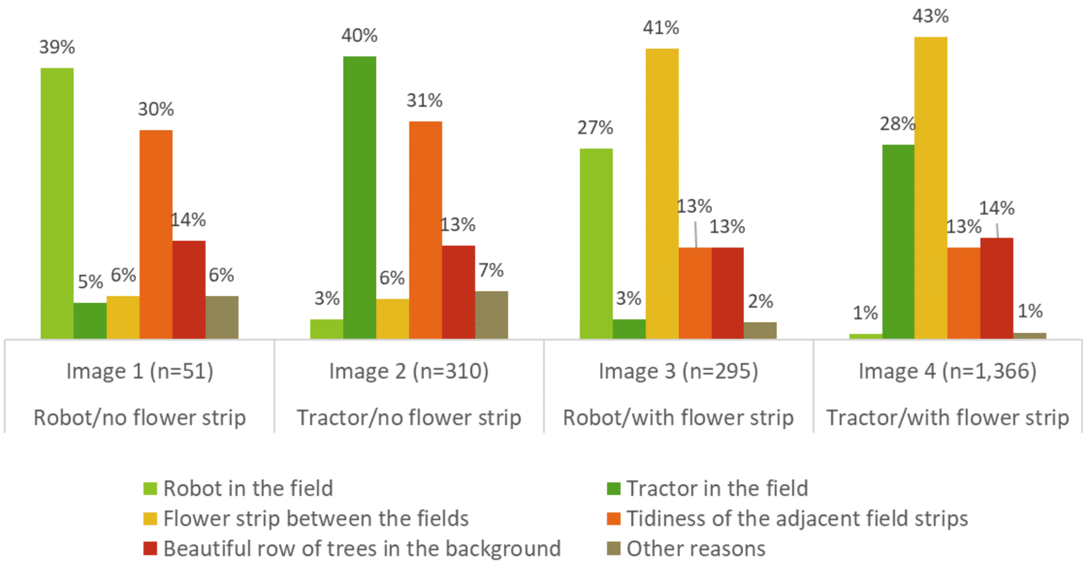

Figure 2: Distribution of preferences and selection motives

Factors influencing preferences

The two binominal logistic regression models examining the influence of sociodemographic characteristics on the selection of images with robots and images with flower strip demonstrate distinct effects. Gender influences the selection of images with the robot (Table 2) as female participants are significantly less likely to choose images with a robot compared to men (Odds Ratio = 0.434). If respondents have personal contacts with acquaintances in the agricultural sector, the likelihood of selecting the robot image is significantly lower. Interestingly, respondents with personal agricultural experience exhibit an opposite, though not statistically significant effect. No additional influence factors, such as the attitude towards technology or origin from western or eastern German states, affect the preference for a field robot compared to a tractor.

Table 2: Logistic regression model A 'Field robot'

Predictors Model A Field robot	B	*SE*	Wald	p	Odds Ratio	95% CI LL	95% CI UL
Gender (1=female)*	-0.835	*0.337*	6.137	0.013	0.434	0.224	0.840
Age (1=younger than 40 years)	0.067	*0.392*	0.029	0.864	1.069	0.496	2.304
Education (1=no A-levels and below)	0.100	*0.332*	0.090	0.764	1.105	0.576	2.118
Size of place of residence (1=less than 20k inhabitants)	-0.288	*0.342*	0.706	0.401	0.750	0.384	1.467
Region (1=Western Germany states)	-0.314	*0.367*	0.730	0.393	0.731	0.356	1.501
Own agricultural experience (1=yes)	0.405	*0.670*	0.365	0.545	1.499	0.403	5.572
Personal contact with farmers (1=yes)*	-2.088	*1.043*	4.008	0.045	0.124	0.016	0.957
Attitude towards technology (ATT) (negative factor value = higher degree)	-0.034	*0.141*	0.059	0.808	0.966	0.732	1.275
Green Consumption Value (GCV) (negative factor value = higher degree)	0.087	*0.178*	0.239	0.625	1.091	0.770	1.546
Constant***	-1.398	*0.406*	11.892	0.000	0.247		

Note: ***p<0.001, *p<0.05; $\chi^2(9) = 16.460$, p = 0.058; Nagelkerke's $R^2 = 0.076$; (Cox & Snell $R^2 = 0.036$) | Total percentage of assignment classification (contribution of predictor variables) = 90.3% | Source: own survey

In the selection or non-selection of images with flower strip, some sociodemographic factors differ from those influencing the machinery aspect in model A (Table 3). Persons younger than 40 are significantly less likely to choose the flower strip compared to older individuals (Odds Ratio = 0.381). The size of the respondent's place of residence also plays a crucial role: a person living in a village or small town (less than 20,000 inhabitants) is almost 1.6 times more likely to choose the flower strip than someone in a more urban environment. Individuals with a less pronounced sustainable purchasing behaviour (negative factor values of the GCV) are less likely to select images with flower strip (Odds Ratio = 0.652).

Table 3: Logistic regression model B 'Flower strip'

Predictors Model B Flower strip	B	*SE*	Wald	p	Odds Ratio	95% CI LL	95% CI UL
Gender (1=female)	0.272	*0.244*	1.250	0.264	1.313	0.814	2.117
Age (1=younger than 40 years)***	-0.966	*0.262*	13.602	0.000	0.381	0.228	0.636
Education (1= no A-levels and below)[a]	-0.228	*0.244*	0.876	0.069	0.796	0.493	1.284
Size of place of residence (1=less than 20k inhabitants)*	0.451	*0.248*	3.305	0.049	1.570	0.965	2.554
Region (1=Western Germany states)[a]	0.519	*0.267*	3.791	0.052	1.681	0.997	2.835
Own agricultural experience (1=yes)	-0.470	*0.431*	1.189	0.276	0.625	0.268	1.455
Personal contact with farmers (1=yes)	0.260	*0.368*	0.499	0.480	1.297	0.630	2.669
Attitude towards technology (ATT) (negative factor value = higher degree)	0.033	*0.104*	0.101	0.751	1.034	0.843	1.268
Green Consumption Value (GCV) (negative factor value = higher degree)***	-0.428	*0.141*	9.146	0.002	0.652	0.494	0.860
Constant**	0.827	*0.312*	7.044	0.008	2.287		

Note: *** p<0.001, **p<0.01, *p<0.05, [a] p<0.1; $\chi^2(9)$ = 37.843, Nagelkerke's R^2 = 0.122; (Cox & Snell R^2 = 0.080) | total percentage of assignment classification (contribution of predictor variables) = 78.7% | source: own survey.

Evaluation of short associations

For the evaluation of the short associations, the most frequently selected image 4 ('tractor / with flower strip', Table 1) was used. The mentioned keywords were assigned to a category system developed as part of the analysis, and the respective mentions were counted. Depending on which image component was decisive for the participants in choosing image 4, there were different frequencies of assignments to the categories. Table 4 shows the most frequent assignments in the category system, indicating the rank for the main components 'flower strip', 'tractor', and 'the tidiness of the adjacent field strips'. With the flower strip being the main motive for choosing image 4, it is predominantly associated with a functioning ecosystem (green/nature/environment). Within this category, numerous keywords refer to 'biodiversity', 'species diversity', and 'habitat for insects and bees'. The second most frequently mentioned keywords relate to the aesthetics of the landscape, such as 'colourful', 'idyllic', 'beautiful', or 'vibrant'. The third most frequently used category for the flower strip includes terms that express well-being, such as 'joy', 'peace', 'life', 'friendliness', 'strength', or 'harmony'. Other frequent mentions can be categorized under variation ('no monoculture'), soil and soil protection, neat and tidy ('separated'), relevance/useful, agriculture in general, season, and familiar image/tradition.

The categories agriculture in general and familiar image/tradition are most frequently associated with the image component tractor and therefore achieve a significantly higher rank than for the flower strip. These two categories include terms that describe agriculture in general and neutrally, such as 'farmer', 'sowing', 'ploughing', or the mention of specific tractor manufacturers. The category familiar image/tradition includes keywords such as 'home', 'familiar', 'known', 'normal', 'original', or 'tradition'. Other frequent associations for the tractor fall into the categories of maintaining jobs and work in general, where the working conditions and activities of the farmers themselves are emphasized. Keywords such as 'human work', 'people', 'workplace', 'craft', and 'good work' indicate a positive evaluation of agricultural activity.

Table 4: Frequencies and ranking of the main categories of keywords mentioned for the three most frequent image components for the selection of image 4

	Image components					
	Flower strip		Tractor		Tidiness of the adjacent field strips	
Association category	**Mentions**	**Rank**	**Mentions**	**Rank**	**Mentions**	**Rank**
Green/Nature/Environment	1,535	1	54	5	25	2
Aesthetics	347	2	21	8	15	4
Well-being	175	3	64	4	17	3
Variation	52	4	0	26	1	9
Soil and soil protection	43	5	5	14	0	13
Neat and tidy	37	6	9	10	49	1
Relevance/Useful	25	7	3	16	1	9
Agriculture in general	23	8	175	1	12	5
Season	21	9	2	20	0	13
Familiar image/Tradition	14	10	91	2	0	13
Nostalgia	11	11	31	6	1	9
Maintaining jobs	3	20	66	3	0	13
Efficiency/Quality	3	20	14	9	5	6
Work in general	2	22	25	7	1	9
Retrograde step/Old	0	30	3	16	2	7
Modern/Trendy/Progress	8	16	2	20	2	7
Total	**2,299**		**565**		**131**	

Further in the ranking, similar frequencies of assignment are shown as for the image component flower strip. Even with the tractor, the categories well-being, green/nature/environment, and aesthetics are frequently occupied. Although the constant image component 'beautiful row of trees in the background' represents the third most frequent mention for image #4 (see Figure 2), frequent evaluations of the landscape image of strip cultivation are also mentioned for the component 'tidiness of adjacent field strips' (see Table 4). The associations with tidiness, in terms of the orderly arrangement of field strips, can mainly be assigned to the category of neat and tidy. Examples of assigned keywords include adjectives such as 'well-kept', 'clean', 'conscientious', 'precise', or 'symmetrical'. Following in the ranking are other categories that are also frequently mentioned in connection with the flower strip, such as green/nature/environment, well-being, or aesthetics.

Discussion and Conclusions

If a small-scale diversified production system offers various ecological benefits, the question arises as to how such production systems should be technologized and designed. This is important to ensure public acceptance and, consequently, consumers' willingness to pay for such production systems and their elements. The evaluations of the preferred images and the decisive individual components suggest overall preferences for natural or near-natural landscape images (e.g., flower strip) among the general population. Furthermore, a 'familiar' image of agriculture (tractor) is also preferred. In the image variants without flower strip, the survey participants chose the tractor more than six times as often as the robot, which may be reflected by the fact, that the use of field robots in agriculture is yet not being widespread and therefore hardly known.

However, the image variant with a robot and flower strip is chosen about as often as that with a tractor but without a flower strip. This aligns with observations from similar studies, which indicate that the use of autonomous machines in the field is not fundamentally viewed critically by society (Pfeiffer et al., 2020) or that the degree of autonomy is considered as secondary to the reduction of herbicides in food production (Spykman et al., 2022). According to the survey responses, strip intercropping, as a production system that changes the familiar landscape image, is not generally rejected. Both with and without flower strip, the visually assessed 'tidiness of the adjacent field strips' received a moderate level of approval and is associated with both an orderly structure and the categories of aesthetics and green/nature/environment. This result of the present study mitigates the conclusions of Laroche et al. (2018), which suggested that natural vegetation in linear structures causes dissonance. However, the additional increase in acceptance of the changed landscape image due to the flower strip aligns with previous findings, which indicate that consumers desire food production to be as "natural" as possible (Zander et al., 2013; Kühl et al., 2019).

The method of querying visual preference with subsequent affect-oriented key words (short associations) serves as a more in-depth source of information about the motivation behind decisions for or against rural landscape components. The mentioned keywords can mostly be assigned to categories considered positive or neutral. Due to the initial question about a preference for an image variant, it is assumed that the respondents almost exclusively mentioned positive or neutral reasons rather than negative exclusion criteria. Thus, negative associations were hardly present, so no conclusions can be drawn about which image components cause rejection and for what reasons. In other studies, on image-based evaluations of production processes in agriculture, for example, free associations without prior preference queries (Kühl et al., 2019; Pfeiffer et al., 2020) or agreement on a scale between two opposing word poles (Busch et al., 2019; Langer et al., 2022) were asked. In the present study (in reference to image 4), the mentioned keywords for the flower strip were mostly assigned to positive association categories. This may not only underscore the subjective well-being or aesthetic aspect of this element for the participants but also its functional importance for environmental and soil protection. The tractor, as another decisive selection element of this specific image, triggers more neutral associations, such as familiarity with this image of agriculture. This neutral evaluation is also reflected in the frequency of more general keywords mentioned regarding agriculture, such as tractor brands or field operations. In addition to the image causing associations with well-being, the tractor is also known to be viewed as a symbol of maintaining jobs in agriculture (Pfeiffer et al., 2020). However, the low mention of the image component 'robot' by those participants who selected an image with a tractor (Figure 2) suggests that the choice was not made due to the rejection of the robot.

A preference for autonomous field equipment based on the selection of images showing a field robot can be demonstrated for certain characteristics in the population. While age and education level do not play a role in our sample, men show a higher likelihood of agreeing to the use of robots in the field than women. Also, a lack of direct contact with agricultural practice seems to be a reason to break away from the familiar image of the tractor and prefer the use of robotics (in the context of strip intercropping). This insight is consistent with social constructivist theoretical approaches, which often postulate that knowledge and views are constructed through social processes and interactions (Gergen, 1985). For the flower strip as the most important reason for image selection, the likelihood of preference increases among older people, those living in rural regions, and respondents who consider themselves “green consumers”. The latter correlation is well established in consumer research literature, which shows that a preference for sustainable consumer products can lead to the non-environmental characteristics of a product or production process also being rated more positively (Haws et al., 2014), even if these are not known in detail. This possibly explains the higher preference for the image of the robot with a flower strip compared to the robot without a flower strip, although further investigations are necessary for a reliable statement in this regard. It can still be assumed that for individuals with a high degree of GCV, the evaluation of the use of autonomous technology is positive, provided it results in more sustainable production methods. The two models explored selected variables influencing preferences for landscape components. Future studies should consider additional factors, such as the population's knowledge of farming practices, experiences, or attitudes towards ecology and nature.

In previous research on field robots, surveys of farmers have already played an important role (e.g., Spykman et al., 2021). Also, studies on the perspectives of manufacturers and stakeholders in the agricultural machinery industry show that the interests of the non-agricultural society and non-human actors such as animals, landscapes, and soil have not yet been adequately recognized as relevant stakeholders (cf. Ayris et al., 2024). Although the approach of Responsible Research and Innovation (RRI), as discussed by Rose and Chilvers (2018) and Regan (2021), primarily emphasizes the social science perspective, the broader ecological context must not be overlooked to also consider the societal perspective on changes in landscape structures. The present contribution thus addresses a crucial aspect for future research: the view of the non-agricultural society on the impacts of changed landscape images due to small-scale production systems and the use of new farming technologies.

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Consumers’ willing to pay a premium for climate-friendly production: Effect of production method and dynamic social norm information

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Extended Abstract

The global food system is a major contributor to greenhouse gas emissions, necessitating a shift towards more sustainable agricultural practices. Climate-Smart Food Systems (CSFS) aim to enhance productivity while reducing emissions, which also depends on consumer willingness to pay extra for these products. This study examined the effect of providing information about climate-smart production and dynamic social norms on consumers' willingness to pay (WTP) a premium for climate-friendly vegetables. This study conducted an online experiment across Denmark, Lithuania, and Spain, dividing 1,568 participants into four groups: control, climate-smart production information, dynamic social norm priming, and a combined intervention group. Results show that 64.52% of consumers who received combined information were willing to pay a premium, compared to 56.65% in the control group. Non-parametric and parametric analyses confirm that the provision of food production method and combined intervention significantly increases WTP extra compared to the control. These findings suggest that integrating information provision with dynamic social norms could encourage consumer demand for climate-friendly products, potentially inspiring the adoption of sustainable agricultural practices through its feedback loop. Thus, considering the use of product production methods and dynamic information while promoting sustainable agricultural product consumption to motivate consumers is suggested.

Introduction

Consumers rely on information-based tools to make sustainable food choices and decide on their premium price for sustainable products. Information about the climate impact of food production and the benefits of climate-smart technologies can increase consumers' perceived value of climate-friendly products, thereby raising their WTP. Social norms, particularly dynamic social norms that emphasize changing consumer behaviors, can also influence consumer decisions by creating a sense of societal approval and description for sustainable consumption. However, the implementation of these interventions may vary in their effectiveness. While some studies suggest that providing information alone can significantly encourage consumers to increase their WTP, others argue that combining social norm interventions with specific information about sustainable innovation may enhance their effectiveness. This study aims to test the individual and combined effects of interventions—information about farmers using climate-friendly smart technologies for production of climate-friendly food and ‘priming dynamic social norm stating that more people are becoming interested in climate-friendly food products—on consumers' WTP for climate-friendly produced vegetables, specifically focusing on carrots produced using precision technologies.

Methods

This study was conducted an online survey experiment across three European countries: Denmark, Lithuania, and Spain. The respondents were randomly assigned participants to four experimental groups: a control group that received no additional information, a group that received information about climate-smart production methods (CSA information), a group that received dynamic social norm priming (SocialN), and a group that received both interventions (Combined). The international survey company Norstat handled the data collection through its consumer panel, distributing the total sample of 1,568 participants across the four experimental groups and three countries. The survey used a payment card method approach to elicit participants' willingness to pay (WTP) extra for climate-friendly carrots, asking respondents to select the maximum premium they were willing to pay for carrots produced using climate-smart technologies. Data analysis involved descriptive statistics (cumulative percentage distributions), non-parametric (the Kruskal-Wallis test), and parametric (ordered probit model) analysis.

Results and Discussion

The results indicate the effect of two interventions on consumers' willingness to pay (WTP) extra for climate-friendly carrots. In the control group, 56.65% of consumers were willing to pay at least a 1% premium. This percentage rose to 61.06% in the group that received information about climate smart production methods, 58.12% in the social norm priming group, and 64.52% in the group that received both interventions. The cumulative percentage distribution analysis highlights that the combined intervention motivates relatively higher proportion of consumers willing to pay premiums compared to the other groups. The non-parametric analysis revealed a statistically significant difference in WTP extra between the control group and the CSA information and combined intervention groups, but not between the control and social norm priming group. The ordered probit model further confirmed the combined intervention's significance in the parametric analysis. Consumers in this group had a higher probability of being in higher WTP categories compared to those in the control group. The findings of this study underscore the importance of combining information provision with social norm interventions to effectively increase consumer demand for climate-friendly food products. In some extent, the information about climate-smart production methods alone might enhance WTP extra, its effect would be significantly amplified when combined with dynamic social norm priming. This suggests that consumers are motivated by the environmental benefits of climate-smart technologies, and the perceived behavior of others within their social group would drive sustainable consumption behavior. The effectiveness of combined information provision in enhancing consumer demand for sustainable product consumption is demonstrated by this study, which could be used as a feedback loop in promoting the broader adoption of climate-smart technologies by farmers.

Presenter Profile

Kassa Tarekegn Erekalo: is a PhD Fellow at the Department of Food and Resource Economics at the University of Copenhagen and has been a visiting researcher at Harper Adams University since August 2024 for a two-month period. He is working on the Behavioural Change towards Climate-Smart Food Systems (BEATLES) EU project (https://beatles-project.eu/), which aims to foster behavioural change towards sustainability within the food system. His PhD research focuses on the decision-making processes of two key actors in the climate-smart food system:

farmers and consumers. His work involves analysing behavioural lock-ins and levers for the adoption of climate-smart agricultural practices and technologies, as well as conducting cost-benefit analyses of selected technologies. Additionally, he explores consumer decision-making, particularly their willingness to pay a premium for climate-friendly production methods. Kassa's primary research interests centre on decision-making within the sustainable agrifood system, with a specific focus on farmers and consumers.

Drivers and Barriers of Digitalisation Adoption to Enable Agroecology

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Extended Abstract

Agroecology has been receiving growing attention in worldwide agricultural policy discourse in recent years. Agroecology is a multifaceted area of study regarded as a science, a set of practices, and a social movement (Sinclair et al., 2019). In the present manuscript, agroecology is intended as the range of practices described in Mouratiadou et al. (2024: p.4). The Food and Agriculture Organisation of the United Nations (FAO) have compiled a list of agroecological principles and developed a protocol for operationalising agroecological farming to contribute to a global transition to increasingly sustainable agri-food systems (FAO, 2018; 2019). At the European level, agroecology is expected to contribute to policy actions such as the "European Green Deal" (COM/2019/640), the "EU Farm to Fork Strategy" (COM/2019/640), the "EU Biodiversity Strategy for 2030" (2020/2273(INI)), and the "2030 Digital Compass: the European way for the Digital decade" (COM/2021/118). European initiatives such as the Agroecology Partnership and the EU's Horizon Europe research and innovation programme are encouraging scientific research, professional training, academic education, creation of stakeholders' networks and adoption of agroecological farming across the continent (Agroecology Partnership, 2024; DG RTD, 2024).

Digitalisation for Agroecology (D4AgEcol) is one of the projects supported by EU's Horizon Europe to provide knowledge for the European transition to agroecological farming (D4AgEcol, 2024). Among its objectives, D4AgEcol aims to holistically evaluate the impact of selected digital tools on agroecology and identify drivers and barriers to the widespread adoption of agroecologically desirable farm technology in Europe. This manuscript is a summary of four multi-criteria assessments of agricultural technology spanning a variety of field operations and production systems. These include: (i) a seeding and weeding robot employed for autonomous mechanical weeding (AMW) in row and broadacre crops; (ii) an uncrewed aerial vehicle (UAV) used for pesticide spraying in perennial crops; (iii) farm machinery retrofitted for autonomous strip intercropping in broadacre crops; and (iv) a virtual fencing system for precision livestock management on intensive and extensive grazing farms. These examples provide a range of insights into the motivations and challenges of adopting digital technologies to enable agroecological farming in Europe.

Methods

The multi-criteria technology assessments here summarised were carried out with the Hands Free Hectare Multi-Objective Linear Programming (HFH-MOLP) model developed as part of the D4AgEcol project. The HFH-MOLP model is a decision-making support tool solving problems of whole-farm resource planning in situations of conflicting economic, social, and environmental objectives. It quantifies the unwanted deviation from one or more farm-level targets following the goal programming approach described in Hazel and Norton (1986: p.72).

The HFH-MOLP model is an expansion of the single-objective Hands Free Hectare Linear Programming (HFH-LP) model developed by Preckel et al. (2019) and later adapted by Lowenberg-DeBoer et al. (2021).

In the HFH-MOLP model, the importance of individual objectives is represented by weights reflecting the priorities of specific decision-maker profiles (e.g., a profit-focused farmer or an ecology-oriented farmer). The model is solved via the General Algebraic Modelling System (GAMS Development Corporation, 2023) to estimate decision-maker utility across whole-farm plan choices and thus identify the best compromise among compared alternatives. Each objective is composed of one or more criteria whose achievement is quantified via a range of linear equations and normalised over an optimal or worst target value depending on the direction of the utility function associated with each criterion. The criteria used in the HFH-MOLP model are based on the FAO's Tool for Agroecology Performance Evaluation (FAO, 2019). These criteria are quantified via indicators that are selected depending on the technology under investigation, the agricultural system where it is employed, and the motivations and challenges expected to play a role in its adoption. The general analytical framework of the described multi-criteria technology assessments is provided in Figure 1. For more information on the HFH-MOLP model, see Maritan et al. (2023; 2024).

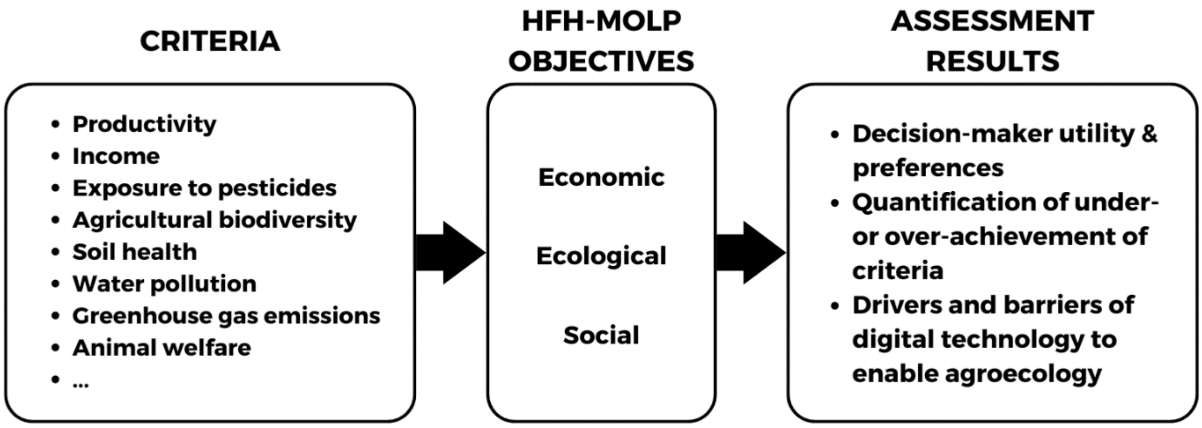

Figure 1: The general analytical framework of a multi-criteria technology assessment conducted via the HFH-MOLP model. The full list of assessable criteria can be found in FAO (2019).

Results and Discussion

The first multi-criteria technology assessment focused on a preliminary analysis of AMW in row and broadacre crops (Maritan *et al.*, 2023). This assessment quantified economic and ecological farm objectives based on farm return, greenhouse gas emissions and deep soil compaction indicators. It was assumed that a UK farmer cultivating sugar beet and a range of cereal, oilseed and protein crops on 295 hectares aimed to reduce its reliance on herbicides by adopting a seeding and weeding robot. Four scenarios implementing two different farm equipment types and two weed control strategies were compared. The equipment types were either conventional (i.e., human driven) or autonomous. The two weed control strategies included conducting AMW in sugar beet and spraying herbicides on other crops, or using AMW for all crops. For all tested decision-maker types, the preferred alternative was the autonomous equipment scenario restricting AMW to sugar beet. Two identified drivers for AMW adoption were a lower reliance on herbicides and a reduced risk of deep soil compaction. However, the substantial investment required for the AMW system, higher crop production costs, and a greater carbon footprint of the produced commodities outweighed these benefits. Barriers to adoption of AMW could be mitigated by developing multifunctional robotic systems, entering a niche market to fetch premium prices for crops grown without herbicides, and/or improving the technical feasibility and performance of mechanical weeding robots in narrowly spaced broadacre crops.

The second case study assessed the economic viability of UAV aerial spraying in Greek vineyards producing winegrapes under current EU regulation (European Union, 2009). This technology assessment included three objectives. The economic objective was quantified by estimating farm gross margins, the ecological objective combined three criteria measuring agricultural biodiversity, soil health and water pollution, while the social objective focused on the risk of pesticide exposure for farm workers. The tested scenarios included two vineyard types and three pesticide spraying variants. The vineyard types were a highly mechanised 8-hectare flat vineyard and a less mechanised 3-hectare steep slope vineyard. Pesticide spraying variants included status quo practices (i.e., vine sprayer on the flat vineyard and backpack sprayer on the steep slope vineyard) and either UAV broadcast spraying or UAV spot-spraying. UAV spot-spraying was the preferred treatment in all scenarios except for the profit-oriented farmer on the highly mechanised flat vineyard. This was because the flat vineyard gross margin achieved while spraying pesticides with a vine sprayer was 11-16% higher than in the UAV spraying scenarios. On both vineyard types, UAV spot-spraying drastically reduced negative impacts on human health and the environment. On the steep slope vineyard, gross margins were comparable regardless of the pesticide spraying strategy. Hence, the social and ecological benefits made UAV spot-spraying the preferred choice for all decision-maker types on the steep slope vineyard. Besides the higher winegrapes production costs on the highly mechanised flat vineyard, identified barriers to adoption of UAV spraying regardless of vineyard type included EU regulation currently forbidding this practice and a lack of pesticide efficacy and spray drift studies.

The third technology assessment addressed the practice of strip intercropping conducted with farm machinery retrofitted for autonomous operation. The tested criteria included farm income to quantify an economic objective as well as agricultural biodiversity and soil health indicators to jointly measure an ecological objective. The modelled agricultural system was a 500-hectare cereal and protein crop UK farm. The crops were assumed to be arranged in 2-metre strips to exploit potential inter-crop synergies such as increased yields and lower fertiliser and pesticide requirements. The farmer was assumed to allocate 20% of the land to nectar flower mix strips receiving UK Government direct payments. Tested scenarios included a whole-field sole cropping system (i.e., not arranged in strips), strip intercropping managed with human-driven equipment, and autonomous strip intercropping. The autonomous strip intercropping scenario was preferred by all tested decision-maker types. Strip intercropping increased farm management complexity and labour requirements, but the latter was drastically reduced when using autonomous equipment. Autonomous strip intercropping generated a farm net income 35% higher than the whole-field cropping scenario. Besides, strip intercropping enabled greater in-field biodiversity and a nearly 50% lower risk of soil compaction due to the smaller size of the equipment used to work through the narrow strips. However, because strip intercropping is rarely practiced in Europe (e.g., Galezewski *et al.*, 2022; Jensen *et al.*, 2020), autonomous strip intercropping may be perceived as a combination of two separate innovations i.e., strip intercropping and autonomous farming. An additional barrier is the unavailability of accurate data documenting potential inter-crop synergies, which could help farmers better perceive the benefits of strip intercropping.

The fourth case study focused on virtual fencing technology applied to intensive and extensive UK grazing systems. Virtual fencing is an emerging precision livestock farming technology used to manage grazing animals without the need for physical fences. The tested objectives and criteria included farm income (economic objective) and greenhouse gas emissions (ecological objective). The simulated scenarios included a 295-hectare mixed farm located in the UK lowlands and a 300-hectare upland grazing farm with an ecology conservation focus. The lowland mixed farm produced a range of cereal and protein crops, maize silage used as supplementary cattle feed, and beef finishing. Grazing cattle were managed via either set or rotational stocking and with woven wire, electric, or virtual fencing, for a total of three scenarios. On the conservation grazing farm, electric fences were assumed to be impractical or not allowed (UK Commons Act, 2006). Thus, only two scenarios were tested on this farm i.e., set stocking and rotational stocking managed with a virtual fencing system, and both generating income out of a suckler cow enterprise (see Maritan *et al.* (2024) for more details about this study). Regardless of the decision-maker type, the preferred scenarios were rotational stocking using electric fencing on the lowland mixed farm and set stocking on the extensive upland farm. These preferences were mainly dictated by the high adoption cost of virtual fencing negating the economic benefits achieved via rotational stocking. On lowland intensive beef enterprises, electric fencing is a more competitive strategy that could only be outperformed if virtual fencing technology was either made cheaper or more valuable (e.g., by collecting livestock data to enable early disease and/or oestrus detection). Two identified drivers for virtual fencing adoption on extensive grazing farms were lower farm greenhouse gas emissions and the possibility to protect sensitive habitats from grazing animals while maintaining a beef productivity comparable to set stocking.

Conclusion

This manuscript summarised four case studies focusing on the use of agricultural technology to enable agroecological practices related to weed management, pest and disease management, crop and animal diversification over time and space, management of landscape elements, and precision livestock farming. The identified drivers and barriers of digitalisation adoption to enable agroecology differed across technologies, agricultural systems, and practices considered. The main drivers included reduced labour requirements, lower environmental pollution, increased biodiversity and ecology conservation, less risk of soil compaction, and a lower exposure to pesticides for farm workers. On the other hand, substantial adoption costs, higher management complexity and adverse regulation are barriers that must be overcome to enable the widespread adoption of agroecological farming in Europe. Creating a conducive regulatory environment could lead to the emergence of cost-effective entrepreneurship that would ease the economic and operational burden for potential adopters. Lastly, further research is required to generate data and provide valid evidence for a range of criteria such as the role of digital technologies in mitigating greenhouse gas emissions and improving animal welfare.

Keywords

Precision agriculture; Autonomous mechanical weeding; UAV spraying; Autonomous strip intercropping; Virtual fencing; Multi-criteria decision-making.

Presenter Profile

Elias Maritan is a Research Associate at Harper Adams University working under the supervision of Prof. Karl Behrendt and Prof. James Lowenberg-DeBoer. His research uses multi-criteria decision-making and linear programming methods to analyse economic, environmental and social implications of innovative agricultural technology. He is currently involved with the Digitalisation for Agroecology project, co-funded by UKRI and the EU's Horizon Europe research and innovation programme.

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Practising responsible research and innovation in trans-disciplinary teams: the 'Cultured Meat: Opportunity or Threat?' project

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Abstract

Cultured meat is being promoted as a key emergent technology within alternative protein transitions, which are being supported in many parts of the world. A major project funded by UK Research and Innovation, led by the Royal Agricultural University with partners from academia, the farming industry, and technology companies, set out to understand the possible implications of cultured meat for farmers in the UK. The desire to include farmer voices as a means of incorporating their views into transition trajectories was driven by the principles of responsible research and innovation [RRI] (Stilgoe et al., 2013). Responding to calls for emergent agricultural technologies to be responsible (Fielke et al., 2022; Rose et al., 2022), and specific concerns around the lack of transparency and power imbalances within cultured meat production (Guthman and Biltekoff, 2021; Sexton 2022), the two-year project was designed to include farmer voices in anticipating the potential impacts of cultured meat. However, the literature has illustrated the challenge of translating an ambition to do RRI into practice (Glerup et al., 2017; Pansera et al., 2020; Ten Holter et al., 2023). These challenges have been highlighted in research projects on many different topics, including emergent agricultural technologies (Alexander et al., 2024; Burch et al., 2023; Prutzer et al., 2023), but not yet within a project on cultured meat. The cultured meat project set out to include a wide range of farmer voices, drawing on multi-disciplinary expertise and a stakeholder advisory panel.

Based on 15 interviews of its researchers and stakeholder advisory board, as well as analysis of meeting minutes, this paper reflects on how the project attempted to practise RRI, as well as exploring the challenges to realising it. Though analysis is still ongoing, early findings suggest that the project was able to implement several aspects of research practice aligned with RRI, including a range of farmer voices, carefully anticipating the effects of emergent technologies, and utilising stakeholder advisors to check assumptions. The most significant challenges related to including 'harder-to-reach' farmer voices, reconciling disciplinary differences and staffing changes, working within relatively constrained funding rules, managing a large stakeholder advisory panel who had different worldviews and interests, and not choosing to carry out specific training on RRI for the whole consortium. The paper will reflect on the lessons to be learned for other research teams seeking to translate RRI ambitions into practice.

Keywords

Alternative proteins; Cultured meat; Farmers; Protein transitions; Responsible Research and Innovation.

Presenter Profile

David is a Rural Geographer and Elizabeth Creak Chair in Sustainable Agri-Food Systems at Harper Adams University. His group conduct research on change in agriculture with a focus on helping farmers adapt to changing policies and societal demands. Areas of interest include technology adoption, behavioural interventions for change, and the ethics of new technologies. The group also conducts research on helping farming families cope with change with a focus on improving the landscapes of support for mental wellbeing. David has published over 75 peer reviewed research papers, been invited to give oral evidence in Parliament three times, and written major reports for Defra, Welsh Government, the AHDB, FAO, and the OECD. He was a 2023-24 Fulbright Scholar at Cornell University.

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Keynote: What Does Agri-tech Entrepreneurship and Venture Capital Offer for Sustainability Transitions?

Dr. Steven Wolf

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Presenter Profile

Steven Wolf studies environmental governance (i.e., interplay of state and non-state actors in environmental (mis)management) at Cornell University (USA). His teaching and research focus on the implications of real and imagined state (public), market (private) and community (collective) coordination mechanisms applied to agriculture, forests, and environmental change. Recent collaborations with students and postdoctoral researchers focus on India, China, Mexico, and USA. Current work centers on analysis of accountability relations and lack thereof. He is Past President of RC40, Research Committee on Agriculture and Food, International Sociological Association.

Willingness to pay for pest management information: A case study of specialty crop growers in the US

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Abstract

This study uses US specialty crops survey data with a choice experiment and the generalized mixed logit model to assess the value growers place on pest management smartphone apps. Preliminary results indicate that growers consider smartphone tools as a normal good and that including historical pest information on their farms and pest prediction accuracy of 92% significantly affects willingness to pay. We also find that growers prefer information to come from educational/research institutions and private agricultural companies rather than government agencies. We estimate that growers are willing to pay $187.43/month for pest management smartphone apps with high predictive power and farm-level historical pest information.

Keywords

Risk-prediction models, pest management, specialty crops, willingness to pay.

Presenter Profiles

Dr. Tara Wade is an agricultural resource economist and assistant professor at the University of Florida, Food and Resource Economics Department, and the Southwest Florida Research and Education Center. She specializes in the economic evaluation of conservation practices and technologies that help to maintain or improve water quality and soil health. Dr. Wade uses survey data and a suite of discrete choice analysis methods to model grower adoption behavior and identify the factors that affect adoption (including adoption barriers) and growers' willingness to pay for practices. This information is applied to assess the tradeoffs, costs, and benefits related to adoption.

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Introduction

Pests and diseases are major challenges facing crop producers, which are exacerbated by climate change and the increasing cost of control methods (Vidavksi, 2007). To address this issue, pest management has focused on integrated pest management, organic and sustainable pest management, the role of technology, and socioeconomic and policy to mitigate the impact of pests and diseases (Gouin and Grafton, 2018). Although researchers have focused on the adoption and policy aspects of pest management technologies, like smartphone apps, they have not considered the value placed on these technologies by the growers who use them. Understanding the value growers place on technology attributes is crucial to designing technologies that growers are likely to adopt and will help inform policies that encourage the use of technologies that help minimize pesticide use and improve farm productivity.

This study assesses the value specialty crop growers place on pest management information. These crops are typically high-value and critical to the nation's food security. For instance, tomatoes are a widely cultivated and economically significant vegetable in the U.S. In 2022, tomatoes were among the top three crops harvested and had the highest total production, accounting for 27% of the total utilized production in that year (USDA-NASS, 2023). The tomato industry is threatened by pests and diseases that are often introduced by whiteflies, which can lead to substantial economic losses (Polston and Lapidoth, 2007). Growers often struggle to manage whiteflies because they cannot accurately estimate the whitefly population and potential disease prevalence, causing uncertainty in production costs and yields (Bian, 2020). Risk prediction models serve as a timely pest management information tool to address whitefly population and virus incidence among crops in the field (Anco et al., 2020). When incorporated into farm smartphone applications, this technology functions as a decision support tool (DST) that assists growers with additional information for decision-making under uncertainty (Bonke et al., 2018; Shtienberg, 2013). Of the 1,140 agricultural mobile apps, 58% are for farm management (Costopoulou et al., 2016). These apps span various agricultural categories, and their presence has led researchers to investigate growers' willingness to pay (WTP) for apps that assist with crop protection and irrigation (Bonke et al., 2018; Jaafar & Kharroubi, 2021).

Although earlier research investigated factors influencing growers' willingness to pay for pest management technologies using a binary dependent variable approach at a specific price level, this study proposes to extend the approach by employing a choice experiment to assess the value placed on pest management technology attributes. Additionally, previous studies have primarily focused on livestock farming and have been conducted in Europe and Asia, with no research on specialty crops. Although agricultural mobile applications have demonstrated increased efficiency and higher profits in the American context, their adoption lags that of other sectors. This study aims to address this gap by examining growers' willingness to pay for pest management information in the form of smartphone applications presented as risk prediction models.

Methods

Choice Experiment

To study how growers value pest management information, we use a risk prediction model (smartphone farm apps) choice experiment (CE) presented to specialty crop growers in the US. The farm smartphone apps were described by price, source of information (data used by the risk prediction model), historical pest (predicting pest presences using historic farm data), and accuracy of pest presence prediction. The fractional factorial design was used to generate 10 choice sets. Each choice set included three choice options: two risk prediction and one non-use.

Estimation

To estimate the value growers place on pest management information in CEs, we follow the random utility framework developed by McFadden (1974). We define growers' utility to choose one alternative as $U_{ijt} = V_{ijt} + \varepsilon_{ijt}$, where V_{ijt} is the deterministic part of the utility for farmer i chooses risk prediction model j in choice set t and ε_{ijt} is the error term following a Gumbel distribution. The utility function can be simplified to $U_{ijt} = \beta'_i X_{ijt} + \varepsilon_{ijt}$, where, $\beta_i = \theta_i * \beta + [\gamma + \theta_i(1+\gamma)] * L * u_i$ and $\theta_i = \exp\left(-\frac{\tau^2}{2} + \tau * w_i\right), w_i \sim N(0,1)$. This model combines scaled multinomial logit; scaled error parameter ($\tau = 0\ and\ L \neq 0$), $\beta_i = \beta + L * u_i$ and mixed logit model ($\gamma = 0\ and\ L = 0$), $\beta_i = \theta_i * \beta$, where there is heterogeneity in preferences, known as a generalized mixed logit model. These methods, allow us to capture WTP estimates and compare heterogeneity and scaled parameter effects with a nested generalized mixed logit model.

Data

All data used in the study are preliminary and come from a survey of US specialty crop producers—data collection is ongoing. The survey was administered by Qualtrics in February 2024 and resulted in 250 completed surveys. Vegetable and pulse growers represent about 40% of the sample, farms with less than 1000 acres represent 97.2%, 81.6% of respondents are male, 91% are white, and 3% are African American. The sample is representative of the US specialty crop grower population in terms of crops grown, race, and acres (USDA-NASS, 2019).

Results and Discussion

Preliminary results from the generalized multinomial logit preference model are presented in Table 1 and suggest that growers regard all attributes of the pest management technology as highly relevant, with estimates being significantly different from zero at the 10% level or lower. Moreover, the significance of tau, which captures the scale heterogeneity of preferences, indicates that growers weigh each attribute differently (Liu et al., 2019).

The price estimate is negative and significant at the 1% level. This means that an increase in the price of a smartphone agricultural app reduces growers' utility/preference provided by the choice. Likewise, the alternative specific constant or status quo is negatively significant at the 1% level. This indicates a disutility from not choosing any available smartphone app options. In contrast, regarding the source of information used by pest management technology, growers have a positive preference for educational/research institutions and private agricultural companies that provide data for pest presence predictions. However, growers prefer educational/research institutions (0.762) to private agricultural companies (0.610), with government agencies as the reference attribute. Past pest presence on farms has a positive and significant coefficient, implying a higher utility/preference by growers when the historic pest feature is included in a choice. Regarding the predictive accuracy of smartphone pest management technology, growers prefer a higher predictive technology option to lower-tier options: the coefficient of 92% accuracy (1.244) is significantly different from the reference case, 77% accuracy. The negative significance of the alternative specific constant (or the status quo) indicates that growers consider smartphone tools as a normal good. This suggests a disutility from not choosing any available smartphone app options.

The individual WTP mean estimates (Table 2) illustrate that growers are willing to pay the most for historical pest presence consideration ($23.02/month), followed by 92% accuracy ($15.67/month). Growers are willing to pay $187.43/month for smartphone pest management apps.

Table 1: Preferences Estimates for Smartphone Pest Management Applications

Variables	GN Mixed Logit Parameters
Price	-0.0794***(0.021)
Educational/Research Institution	0.762***(0.275)
Private Agricultural Company	0.610**(0.266)
Historical Pest	1.828***(0.444)
Accuracy: Ninety-Two	1.244***(0.377)
Accuracy: Eighty-Eight	0.466*(0.238)
None/Status Quo	-14.885***(4.148)
Tau	-1.146***(0.180)
Gamma	-0.224**(0.094)
Log-Likelihood	-889.42
Observations	1250

Note: Standard errors in parentheses, *** 1%, ** 5%, and * 10% significance level.

Table 2: Mean WTP Estimates for Smartphone Pest Management Technology Attributes

Variables	GN Mixed Logit	
Educational/Research Institution	9.605***	(2.847)
Private Agricultural Company	7.677***	(2.875)
Historical Pest	23.025***	(3.102)
Accuracy: Ninety-Two	15.671***	(3.345)
Accuracy: Eighty-Eight	5.862**	(2.666)
None/Status Quo	-187.435***	(32.033)
Observations	250	

Note: Standard errors in parentheses, *** 1%, ** 5%, and * 10% significance level.

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Economics of labour saving agri-tech for smallholder farms: The case of Bangladesh

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Abstract

Bangladesh agriculture has been quite successful in primary tillage mechanization with two-wheel tractor operated machines (2WM) and threshing with stationary threshers but rising farm wage rates and labour scarcity push farmers toward further mechanisation. The Bangladesh government has encouraged whole farm mechanization to support food security, but the cost-effective pathways for mechanization are not yet supported with evidence-based policy. The primary short run alternatives are whole farm 2WM mechanization and whole farm four-wheel tractor operated machine (4WM) mechanization. In the longer run use of labour saving agri-tech automation, such as drone spraying and autonomous machines may have many advantages. This preliminary study hypothesized that whole farms retrofitted 2WMs for autonomy would make smallholders' cereal farming profitable compared to typical 2WM partial mechanization with human drivers. Retrofitted 2WMs are precision agriculture technology because they have the potential to cost effectively increase the precision of input applications and to collect detailed data. To test the hypothesis, this study estimated field times (h/ha) and field efficiency (%) using typical and ex-ante conventional and autonomous 2WMs. Profitable farm decision was analysed using the 'steady state' Hands-Free Hectare-Linear Programming (HFH-LP) optimization model for 1 ha, 2 ha, 3 ha, 5 ha and 7 ha cereal farms. The analysis compared five mechanization scenarios (i.e., mechanized tillage with other operations manual; mechanized tillage and harvesting with other operations manual; mechanized tillage, planting and harvesting with other operations manual; mechanized whole farm operations; and retrofitted autonomous whole farm mechanization). It was found that mechanized whole farm operations were the most profitable solution for larger 3, 5, and 7 ha farms. Higher wage rates and increasing labour scarcity made autonomous farming profitable in these resource scarce scenarios. The findings indicate that conventional 2WMs could be the short-term solution, but Bangladesh should consider autonomous 2WMs in the longer term.

Keywords

Agricultural mechanization, two-wheel machines, economics of size, profitability, smallholders' agriculture, monoculture.

Presenter Profile

Professor James Lowenberg-DeBoer has over 30 years of worldwide experience in agricultural research, teaching, outreach and leadership. His research focuses on the economics of agricultural technology. He was the former president of the International Society of Precision Agriculture (ISPA) and co-editor of the journal Precision Agriculture. He is a pioneer in the use of spatial regression in analysis of crop sensor data with published work in this area. From 2004-2015 he was the Associate Dean and Director of the Purdue International Programs in Agriculture (IPIA). He is in the staff of Harper Adams University in the United Kingdom.

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All for One and One for All: A Simulation Assessment of the Economic Value of Large-Scale On-Farm Experiment Network

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Abstract

While on-farm experiments offer invaluable insights for precision management decisions, their scope is usually confined to the specific conditions of individual farms and years, which limits the derivation of more broad and reliable decisions. To address this limitation, aggregating data from multiple farms into a comprehensive dataset appears promising. However, the quantifiable value of this experiment network remains elusive, despite the common agreement of the existence of this value. This study conducted a simulation-based assessment of the economic value of large-scale on-farm experiments, using crop variety selection as a case study. A hypothetical region was simulated comprising one thousand corn production fields of diverse soil types and weather conditions. Each field was implemented with an on-farm variety trial. Yields for each variety were simulated based on presumed true yield responses to soil types and weather conditions that are derived from historical Mississippi variety trial data. By constructing aggregated on-farm experiment data set of farms, the individualized optimal variety for each field was recommended, and the associated yields were predicted. The production profitability for all fields was calculated based on current market prices. Results revealed a substantial improvement in farming profitability when employing the individualized optimal variety selection derived from the large-scale experiment network, compared to the scenario of only using farm's own data. Furthermore, the simulation study also reveal that the profitability improvement diminishes when the scale of the experiment network decreases or when the number of trial varieties per field reduces. The simulation results underscored the economic benefits of broader farmer participation in on-farm experiment network and more intensive trials by each participant.

Keywords

On-farm Experiment, Economic Value, Data Aggregation, Simulation

Presenter Profile

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Introduction

The world has been witnessing a constant increasing popularity in on-farm experiments (OFE) during the past few decades. Farms often implement randomized trials in part of one production field, and the data generated from this type of trials are more relevant to the actual production conditions compared to the traditional research site data. However, while on-farm experiments offer invaluable insights for farming management decisions, the scope of the experiment is usually limited. Individual farms normally do not have the resources to conduct large-scale experiments. While each field's crop growth conditions and each year's weather conditions are different, deriving broad and reliable decisions from experiments of a few individual fields is challenging.

To address this limitation, aggregating data from multiple farms into a comprehensive dataset appears promising. This is a commonly recognized idea, and numerous research programs and commercial start-ups have been established to build a farms' network to coordinate the on-farm experiments and share the data. However, due to the various difficulties in technical, institutional, and legal matters, building such kind of network is not easy and demands large effort. On the other hand, the exact return of this on-farm experimentation network is still unclear to the farmers, despite the common agreement of the existence of this value. Demonstrating the quantifiable value of this experiment network will provide important evidence to the farmers to make more informed decisions on whether to join the effort of the network. Unfortunately, there are rarely any studies to estimate the economic return of the on-farm experiment network. Consequently, in the current practice, farmers' participation of the network usually depends on the companies' salesmanship or the farmers' personally relationship to the companies.

Indeed, quantifying the exact economic return of the on-farm experiment network is extremely difficult. Essentially, the return of on-farm experiments come from the value of improved farming decisions generated from the data collected from the experiments. Therefore, the accurate estimation of the return requires the accurate prediction of yield outcomes when applying the decisions. In theory, the best information needed here is to know the true crop yield response function, or a very close estimated function. However, that true response function is almost always practically unknown. Researchers often use the estimated response function, which is the same function that derives the farming decisions, as a substitute for the true function. But obviously that substitution will inevitably lead to biases in the economic return estimation. Furthermore, another challenge is lack of the full set of yield impacting factor data (soil, weather, management, etc.) in the production fields, especially since each field's data can be very different. Due to those limitations, there is still no clear answer of how big the economic return is for farmers to build a on-farm experiment network, and whether it is worthwhile of spending the effort to do so.

This study aims to provide a simulation-based assessment of the economic return of on-farm experiment network. The simulated on-farm experiments are corn variety selection trials. The yield responses to varieties are discrete functions, which are relatively simpler in the response functional form than the more commonly tested response factors such as nitrogen fertilizer, irrigation, or seeding rates, and therefore the optimal decision-making is straightforward. But the same simulation framework can easily be extended to other response factors in future studies. The assumed true underlying corn yield responses to corn hybrid varieties are calibrated based on the historical data of the Mississippi Corn Variety Trials. Therefore, the economic return simulation is not entirely imaginary but instead is backed by some realistic ground truth data. A total of 200 farms are simulated in a hypothetical region, where each farm is facing a decision of choosing from 50 different corn hybrid varieties. The farms selected some fields to conduct on-farm experiments to test the performances of some varieties. A certain number of farms come together to form an experimental network, where the on-farm experiments are coordinated, and the experimental data are shared. The best-performing varieties are chosen and are grown in all production fields in the next year. Yield and profit of each field is simulated based on the assumed underlying true yield response functions. The economic return of on-farm experiment network is measured by the regional average profit increase with the help of the network.

Methods

A hypothetical region of 10,000 farming fields is simulated. For simplicity, each field is a perfect square grid, and the fields are laid out in a 100 by 100 grid, which means that the shape of the region is also perfectly square. It is noted that this region does not include land use categories other than crop growing, which is of course over simplified. A future extension is to use the field boundaries of an actual region (e.g., the Mississippi Delta region) as the base of simulation.

Five soil types are assumed to exist in the region. For simplicity, each field only include one soil type. That means each field is uniform, and there is no within-field variability. Again, this is only for simplicity purpose. The number of fields for each soil type is generally equal. The spatial distribution of the soil types is generated through a Gaussian random field process. Figure 1 below illustrates one possible simulated soil type map for the region.

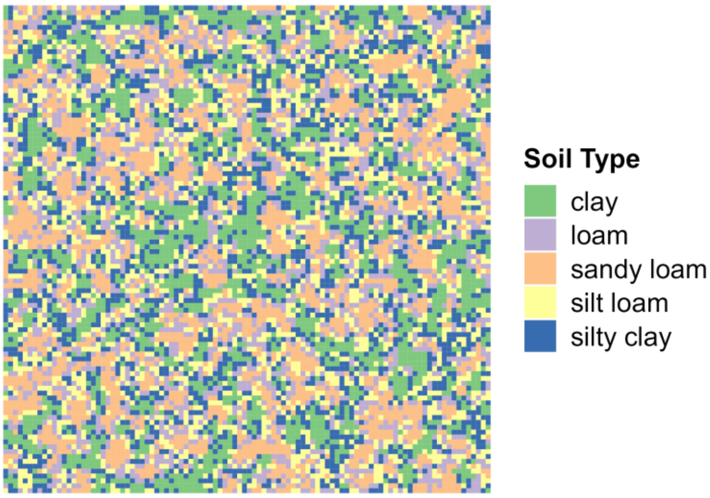

Figure 1: Simulated spatial distribution of five soil types in the hypothetical region.

The rainfall spatial distribution in that region is also simulated through Gaussian random field. Since rainfall amounts are often similar within a region, the spatial variation in rainfall is set to be small. But the temporal variation in rainfall across years is often much larger. Figure 2 shows the simulated rainfall maps for five selected years. Future updates should consider using the actual rainfall data associated with an actual region to make the data more realistic.

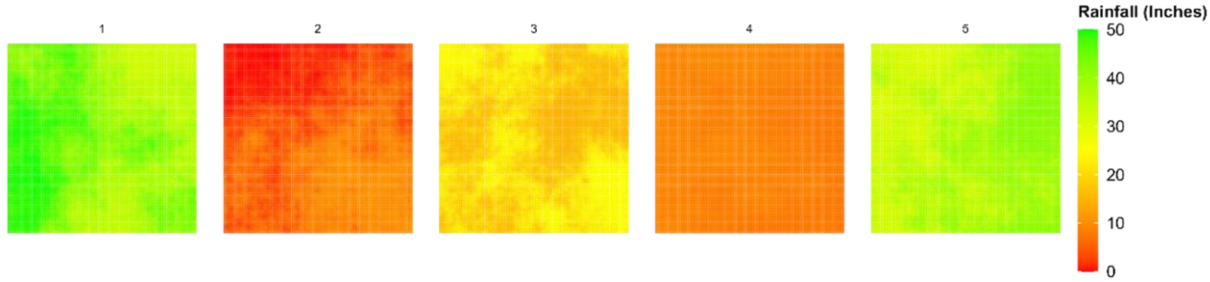

Figure 2: Simulated spatial distribution of rainfall in the hypothetical region for five selected years.

All the 10,000 fields are used for corn production for all years. That is to assume no crop rotations in farming, and corn is the only crop in the region. Suppose in each given year, there are 50 corn varieties available on the market. Each variety's yield performance depends on soil type, rainfall, and the field's individual characteristics. That yield response is assumed to follow a simple linear function:

$$yield^{v} = f^{v}(soil,\ rain)$$
$$= \alpha^{v} \cdot soil + \beta_1^{v} \cdot rain + \beta_2^{v} \cdot rain^2 + \gamma^{v} \cdot soil \cdot rain + \varepsilon^{v} \quad (1)$$

where *v* represents a variety (*v*=1, 2, …, 50), and ε^{v} is a normally distributed random error of yield in each field. The estimation of the response parameters α^{v}, β_1^{v}, β_2^{v}, and γ^{v} are based on the historical data of Mississippi Corn Variety Trials from 2000 to 2022. In each year, around 40 to 80 corn varieties, depending on the years, were tested in 5 to 8 different locations in Mississippi. The testing locations also varied across years, but the pool of locations was relatively stable. The trial sites also recorded soil type and rainfall information.

The estimated yield response to corn varieties, although they are estimations, are used as the "true" underlying yield response functions in the simulation. For convenience, only 50 varieties are selected in the simulation. That is also roughly the average number of varieties that were tested per year. Note that the simple linear response function in Equation (1) is clearly an oversimplification. Future update should consider to use more comprehensive and realistic established crop growth simulation models (like the DSSAT) as the true response functions.

Assume there is a total of 200 farms in the region. All farms are of the equal size, which means each farm has 50 fields. Furthermore, for simplicity each farm's fields cover all 5 soil types, and each soil type has 10 fields.

Each farm picks 5 fields to conduct on-farm experiments, one field for each soil type. It is widely recognized by farmers that on-farm experiments can be helpful for their decision making. But most farms are concerned about the cost and risk of doing on-farm experiments, and usually are only willing to take a small portion of their fields for the experiments. In this simulation study, 10% of a farm's fields are used for experiments, which reflects this practical operation by farmers.

As a baseline situation, it is assumed each farm can test 10 corn varieties. The more varieties to be tested, the more cost and effort for the farmers to take. 10 varieties are an arbitrary number just for simulation purpose. This number can be easily modified for sensitivity analysis. Each experimental field is implemented the same 10 varieties in the testing.

If a farm does not join a network and conducts the on-farm experiments on their own, they can only make variety selection decisions based on their own experimental data. The data analysis is simple. In each experimental field, which represents a soil type, the variety that has the highest yield is the best-performing one, and will be selected as the variety for that specific soil type. Then, in the next year, all fields of the specific soil type in that farm will select that variety. The yield is then simulated based on another year's rainfall data. Since all farms' experiments are individually conducted and farms do not share data, each farm's variety selection results can be very different. Finally, the regional average yield of all 10,000 fields is calculated, and the production profit for the region is computed as well.

Note that in this setting, there are two major sources of errors or risks in the variety selection decisions. The first is the incomplete set of varieties in the testing. As mentioned earlier, the total number of varieties is 50, but each farm is only capable of testing 10. There is a high chance that the best-performing varieties are missing in the testing. The second is the low statistical power due to small sample size. Essentially, each variety's number of observations is only one, which makes it highly vulnerable to yield errors.

In the network scenario, a certain number of farmers can come together to build network to coordinate their on-farm experiments, and also share the experimental data for variety selection decisions. That network can overcome the two limitations of individual experiments as discussed earlier. First, more farms can coordinate the experimental design to include more testing varieties. Second, more experimental fields increase the testing replicates, and therefore improve the statistical power of the data. Consequently, the yield and profitability of the region shall be increased by using the on-farm experiments network. The exact economic return of the network can then be measured by the regional average yield and profit increase by the network compared to the individual experiment scenario.

Results

The simulation process is repeated for 1,000 times. The resulting regional average yields from on-farm experiments of different sizes are shown in Figure 3. The size of network is measured by the number of farms per network. When the size is 1, it means farms are conducting on-farm experiments on their own. When the size is 200, it means the entire region forms one large network that all farmers participate in. Figure 3 shows the baseline scenario where each farm is capable of testing 10 varieties. Not surprisingly, the yield outcome is the lowest when all farms conduct experiments on their own, and increases as the size of experiments network increases, maximizing at network size reaches the largest (200 farms). The yield difference between the largest network and no network is as big as 32.8 bushel/acre, which is very significant. Based on the recent corn price of about $3.87 per bushel, that yield increase translates into about $150 per acre production profit increase. That is higher than many corn growers' total profit margins, and therefore has very large economic significance.

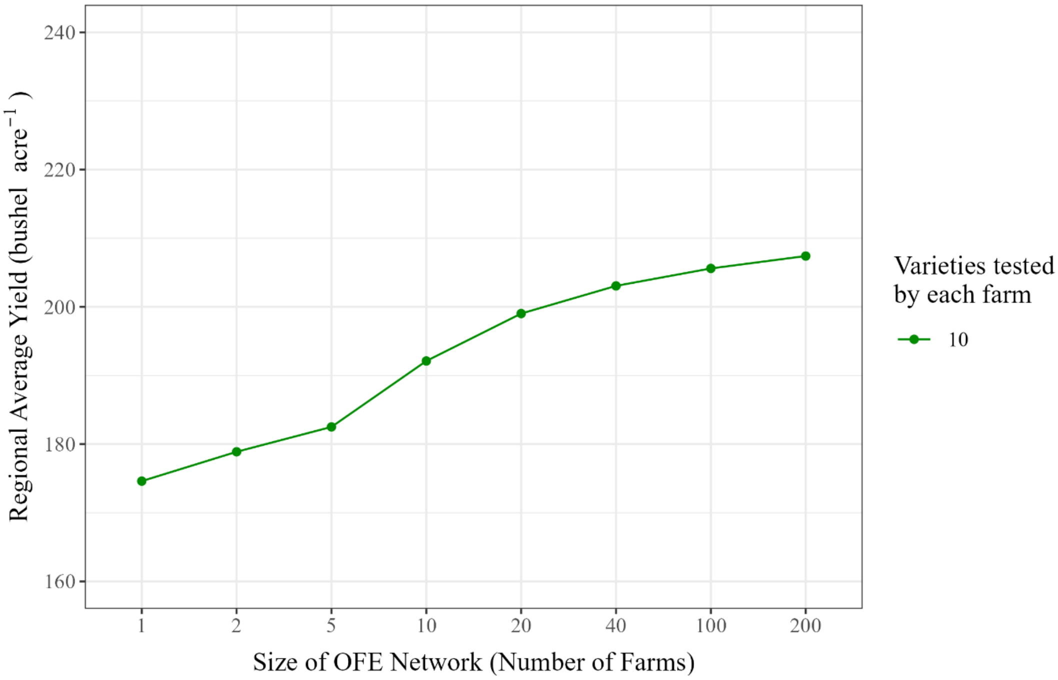

Figure 3: Yield outcomes of on-farm experiment (OFE) network of different sizes, for baseline results from 1,000 simulations.

The above estimated economic returns are of course dependent on the simulation settings. But the rough magnitudes of that return are not changed much when changing the simulation settings. For example, when each farm's variety testing capacity is cut by half to 5 varieties, the yield benefit of the network (200) slightly increases to 34.4 bushel/acre, while when the capacity doubles to 20 varieties, the yield benefit decreases slightly to 28.3 bushel/acre. The details are shown in Figure 4.

The general conclusions also hold when the cross-field variability is smaller, that is, when all fields are more similar. This scenario can be made by reducing the yield error term ε^v. As shown in Figure 5, the yield benefit still increases with the size of on-farm experiment network. However, it is noticeable that the benefit increases quickly drop after the network size passes 5 farms, meaning that when all fields are similar, a small experiment network is sufficient and it is not worthwhile to form a large network.

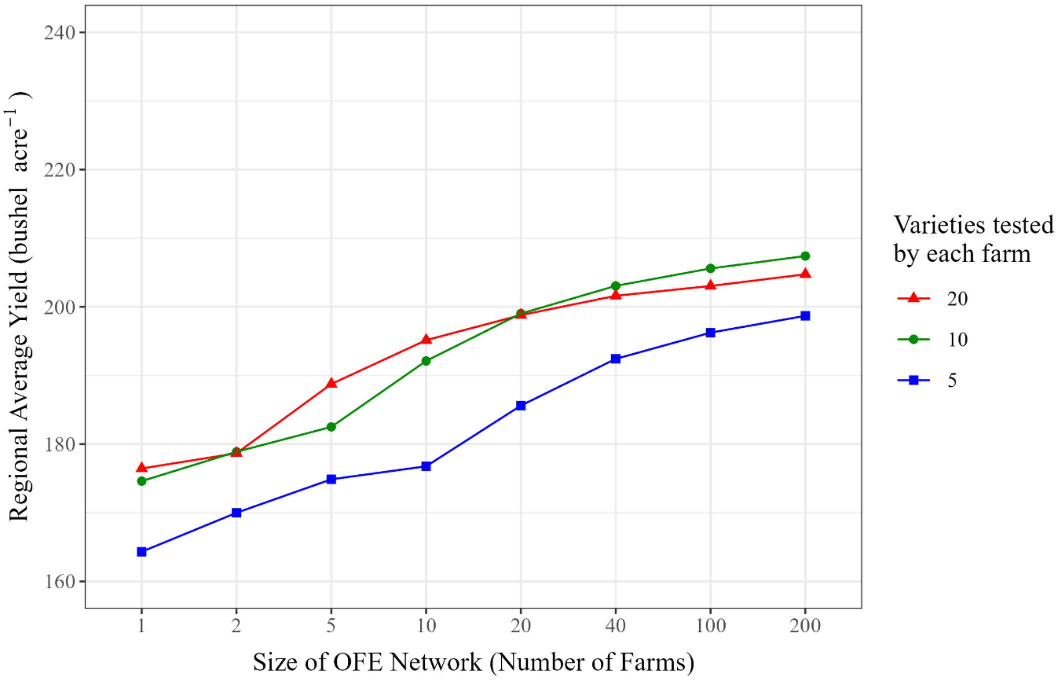

Figure 4: Yield outcomes of on-farm experiment (OFE) network of different sizes, for different variety testing capacities by each farm, from 1,000 simulations.

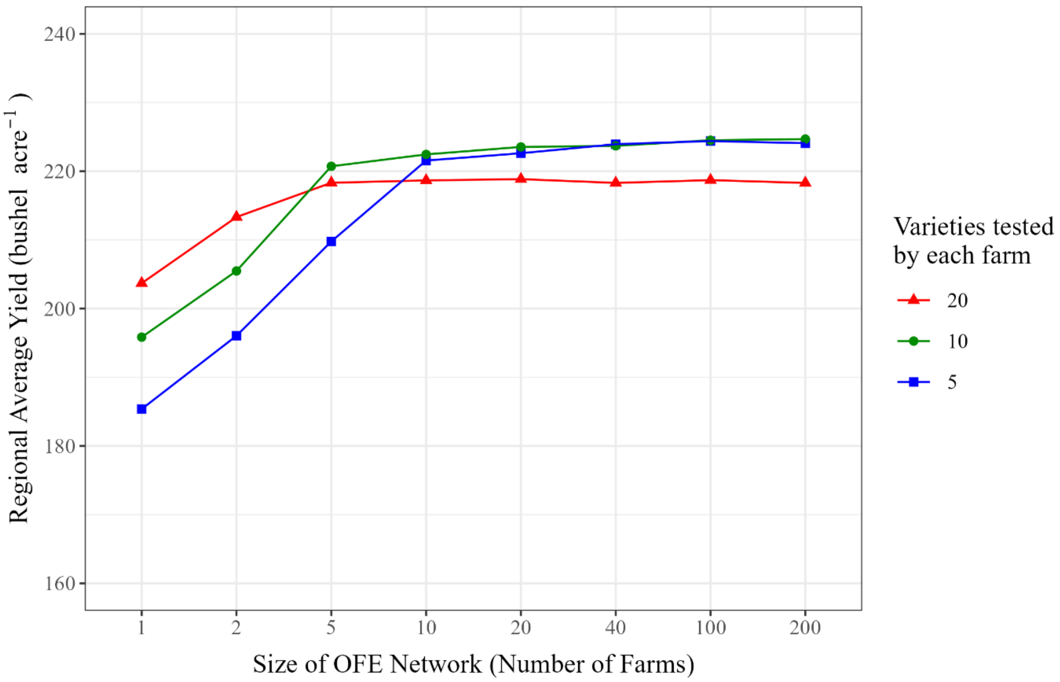

Figure 5: Yield outcomes of on-farm experiment (OFE) network of different sizes, when fields are more similar, from 1,000 simulations.

On the opposite side, if the fields in the region are very different from each other, the benefit of forming large network is much larger. As shown in Figure 6, the average yield increases steadily with network size, especially when the testing capacity of each farm is small (5 varieties).

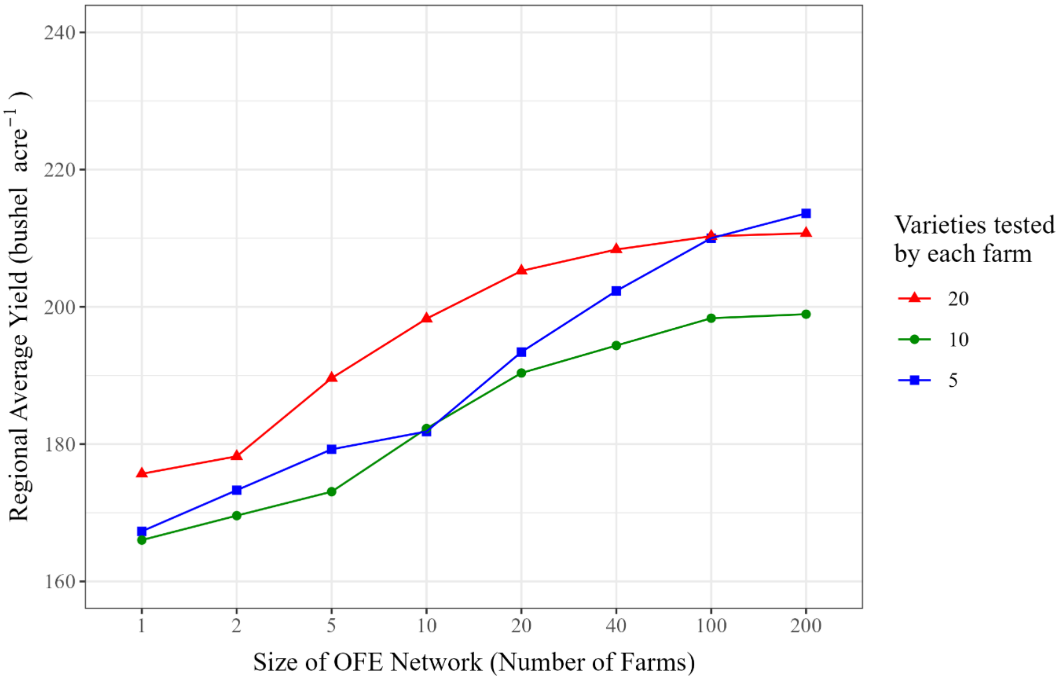

Figure 6: Yield outcomes of on-farm experiment (OFE) network of different sizes, when fields are more variable, from 1,000 simulations.

Discussion

Based on simulated on-farm experiments of corn variety selections, this study provides a quantitative estimate of the economic return of on-farm experiment network. Compared to farms' own on-farm experiments, an entire region's large network can improve the regional average economic return by around $150 per acre, which is highly significant in profit magnitude and justifies the effort to organize the on-farm experiment network. The exact figures of the economic return depend on the simulation settings such as true yield response functions, soil and weather distributions, field similarities, farms' individual testing capabilities, and many others. This study attempts to provide a simulation-based assessment framework to provide some dependable, if not perfect, answers to the pressing questions of how big the benefits of on-farm experiment network is to provide guidance for future directions of agricultural research and industry development.

How fast is Agriculture 4.0 advancing in the UK? An analysis using employment routine intensity

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Abstract

This study explores the adoption rate of Agriculture 4.0 technologies in the UK by analysing changes in employment routine intensity across various sectors from 2011 to 2021. Using the ALM task-based approach and data from the UK Labour Force Survey and Census microdata, we assess the extent of automation in Agriculture relative to other industries. Our findings indicate that the Agriculture sector experienced a modest reduction in routine intensity by aggregating occupation's routine content, suggesting slower adoption of advanced technologies compared to sectors like Information and Communication and Financial Services, which showed substantial declines in routine tasks. The results underscore a broader trend of technological integration in knowledge-intensive industries, whereas Agriculture's lagging pace highlights a potential gap in achieving optimal productivity and efficiency gains through automation. Future research should investigate these findings across different data sources and countries to provide a comprehensive understanding of Agriculture 4.0 in the UK and globally.

Keywords

Agriculture 4.0, job routinisation, task-based approach, routine intensity.

Presenter Profile

Dr. Jorge Campos-González is an Applied Economist specialising in Agriculture, Environment, and Food Economics. He holds a PhD from the School of Agriculture, Policy, and Development at the University of Reading, UK. Jorge's research focuses on technological adoption in agriculture and agricultural employment. He currently works as a Postdoctoral Researcher evaluating the financial and economic impacts of non-farm enterprises in the UK and labour market dynamics in Chile.

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Introduction

The advancement of computing-based technologies has significantly influenced the global digital economy, altering labour across various sectors. In agriculture, the advent of emergent technologies, collectively called Agriculture 4.0, represents a technological revolution for farming activities, which integrates automation, robotics, and data-driven practices, among others. Adopting Agriculture 4.0 brings environmental and economic benefits due to enabling efficient use of inputs and decision-making at the farm level (Rijswijk et al., 2021; Sparrow & Howard, 2021). As agriculture becomes more technology-intense, it increasingly intersects with IT, robotics, remote sensing, etc., expanding the scope and nature of farming-related employment (Ateş & ŞahiN, 2021; Klerkx & Rose, 2020). In the UK, this adoption is being significantly fuelled by private and public initiatives to accelerate the development and uptake of automation technologies to boost productivity, reduce labour demands and promote sustainable agriculture practices.

This study investigates the impact of these technologies across UK occupations and industry structures focusing on Agriculture. However, we could not directly test for Agriculture 4.0-related technologies. Still, we observed trends in routinisation between economic sectors over time and compared them to changes in employment as an indirect test of the adoption of computing-based technologies in the industry. Following the task-based approach pioneered by Autor et al., (2003), the ALM model, we can evaluate the differentiated impact of these technologies on different occupations. The ALM model predicts differentiated implications of computer-based technologies. On the one hand, computer-based technologies can perform job tasks with an intensive demand for routine tasks, both cognitive and manual. Conversely, new technologies complement non-routine cognitive activities, while non-routine manual tasks provide limited substitution or complementarity opportunities. The model assumes that routine tasks can be expressed as programmable rules or as codifiable; in that case, they could be executed by computer-related technologies. Thus, the impact of technological advancements depends on the task composition of occupations, with computer-based technologies biased towards jobs where non-routine tasks are abundant. In contrast, these technologies can substitute for human workers in routine-intensive jobs (manual or cognitive). This study seeks to provide indirect evidence of how fast automation advanced in UK Agriculture between 2011 and 2021 by observing changes in routinisation intensity in employment relative to other industries.

By applying the ALM model differentiation, a relative reduction in the participation of routine tasks within Agriculture over time (relative to other economic sectors) would suggest a more intense use of technological advancements in this industry. In this regard, we aim to document and analyse trends in agricultural employment and their relation to job routinisation. By adapting the published routinisation index by occupation and industry (Perez-Silva & Campos-Gonzalez, 2021; Reijnders & de Vries, 2018) and, using statistics from Labour Force Surveys and Census microdata, we apply these indicators to the UK's employment structure to compare trends between agriculture and other economic sectors. Our findings confirm the current and prevalent narrative that agriculture in the UK is often seen as slow in adopting new technologies (DEFRA, 2022; Lowenberg-DeBoer, J. et al., 2022).

Methods

The analysis starts employing the ALM model, also known as the task-based approach (Autor et al., 2003; Mihaylov & Tijdens, 2019; Perez-Silva & Campos-Gonzalez, 2021; Reijnders & de Vries, 2018;

Spitz-Oener, 2006). The ALM model classifies job tasks for each occupation into five categories: five categories: 1) *routine cognitive*, which involves activities regarding the processing of information defined by explicit rules which can easily be programmable (e.g., record-keeping, repetitive customer service); 2) *non-routine analytic* and 3) *non-routine interactive,* capture labour tasks involving reasoning skills and interactive abilities (e.g., communication and managerial skills), respectively; 4) *routine manual, which refers to repetitive physical work activities (e.g., repetitive assembly)* and 5) *non-routine* manual, which refer to non-repetitive physical work activities (e.g., cleaning services).

By applying the task-approach differentiation, we calculate routine task intensity by occupation, which can be grouped to estimate routinisation intensity across industries. Overall, this estimation includes three stages. First, we estimate the number of people employed in each occupational group for each sector and year. Secondly, the job task classification is applied to the categories proposed by the ALM model to estimate the routinisation measure by occupation. The third stage corresponds to constructing an index, which represents the grouped task content of each economic sector for every year observed.

For the first stage, we combine employment by industry statistics from the Labour Force Survey for the UK (Office for National Statistics, 2024), and microdata samples from Census 2011 and Census 2021 for England and Wales (Office for National Statistics, ONS, 2023a, 2023b). From census data, we identify 25 occupational groups at the 2-digit level and their distribution across industries (1 digit-level). **Error! Reference source not found.** compares e mployment frequencies across various industries in the UK between 2011 and 2021. *Agriculture, forestry, and fishing* experienced a significant decline of 19.6%, dropping from 356,839 to 286,803 employees. In contrast, industries like *Information and communication*, and *Professional, scientific, and technical activities* saw remarkable growth rates of 47.2% and 45.8%, respectively. *Mining, energy, and water supply* increased by 15.1%, while *Financial and insurance activities* grew by 23.6%. *Manufacturing* and *Construction* also witnessed 3.5% and 5.4% declines, respectively, albeit less pronounced than in Agriculture. Overall, the data highlights a trend towards significant employment growth in knowledge-intensive and service-oriented sectors, with agriculture standing out for its notable reduction in employment over the decade.

For the second stage, we use published routinisation indexes by occupation i, $OccRI_i$, (Perez-Silva & Campos-Gonzalez, 2021; Reijnders & de Vries, 2018), which are based on task descriptions reported in the International Classification of Occupations (ILO, 2012). $OccRI$ adds the proportions of cognitive and manual routine tasks. We map $OccRI$ estimates to the current UK occupational structure identified in the first stage and we categorize the occupations in Low, Medium and High routine intensity using the next $OccRI$ ranges: 0-0.4, 0.41-0.75 and 0.76-1, respectively, as indicative the degree of automation to which an occupation would be exposed or automation risk (Frey & Osborne, 2017; Rivera, 2019). Once we identified the 25 groups, we computed the share of each occupation i in each industry j, $ShOccInd_{i,j}$. Next, in the third stage, we multiplied these shares by their $OccRI_i$. The results are aggregated to estimate an indicator of routine intensity at the industry level, which we call $IndRI$. Therefore, $IndRI$ corresponds to the weighted sum of total employment by industry, with $OccRI$ acting as a weight, as follows:

$$IndRI_{j,t} = \sum\left(ShOccInd_{i,j,t} * OccRI_i\right),. \qquad (1)$$

where t stands for time. We compute IndRI to measure the extent of routine tasks by industry in 2011 and 2021.

Table 1: All in employment in the UK by industry (Standard Industrial Classification, SIC, 2007) in Q1 2011 and 2021 (thousands).

Industry	2011	2021	Growth rate (%)
Agriculture, forestry & fishing	357	287	-19.6%
Mining, energy and water supply	497	572	15.0%
Manufacturing	2,860	2,760	-3.5%
Construction	2,212	2,093	-5.4%
Wholesale, retail & repair of motor vehicles	4,034	3,775	-6.4%
Transport & storage	1,451	1,506	3.8%
Accommodation & food services	1,472	1,483	0.8%
Information & communication	1,059	1,559	47.2%
Financial & insurance activities	1,179	1,457	23.6%
Real estate activities	299	418	39.7%
Professional, scientific & technical activities	1,857	2,707	45.7%
Administrative & support services	1,299	1,404	8.1%
Public admin & defence; social security	1,875	2,342	24.9%
Education	3,121	3,442	10.3%
Human health & social work activities	3,967	4,467	12.6%
Other services	1,544	1,747	13.1%
Total	*29,084*	*32,019*	*10.1%*

Source: Labour Force Survey (Office for National Statistics, 2024)

Results & Discussion

The mapping of the task content estimation to each occupational group is presented in **Error! Reference source not found.**. The table provides a comprehensive overview of the task content and routine intensity for the UK's 25 2-digit occupational groups, measured by the $OccRI$ measure, categorising occupations into Low, Medium, and High routine intensity, indicating their susceptibility to automation. Low routine intensity occupations include roles such as *corporate managers and directors* ($OccRI$=0.051), *Science and technology professionals* ($OccRI$=0.026), and *Health professionals* ($OccRI$=0.047), characterised by high proportions of analytical and interactive non-routine tasks. Medium routine intensity occupations ($OccRI$ between 0.41-0.75) include *Culture, media, and sports* occupations ($OccRI$=0.451) and *Process, plant, and machine operatives* ($OccRI$=0.568), featuring a mix of non-routine and routine tasks. High routine intensity occupations ($OccRI$ greater than 0.76) such as *Administrative occupations* ($OccRI$=0.879), *Secretarial occupations* ($OccRI$=0.879), and *Transport operatives* ($OccRI$=0.88) are predominantly engaged in routine cognitive and manual tasks, making them more susceptible to automation. This categorisation highlights the varying degrees of automation risk across different occupational groups.

Table 2: Task content and routine intensity of the UK's 25 2-digit occupational groups.

2-dig Code	Name	Task proportions by task category: analytical non-routine	interactive non-routine	cognitive routine	manual routine	manual non-routine	OccRI	Routine intensity
11	Corporate managers and directors	0.367	0.582	0.051	0	0	0.051	Low
12	Other managers and proprietors	0.533	0.333	0.133	0	0	0.133	Low
21	Science, research, engineering and technology professionals	0.821	0.154	0.026	0	0	0.026	Low
22	Health professionals	0.535	0.372	0.047	0	0.047	0.047	Low
23	Teaching and other educational professionals	0.39	0.512	0.098	0	0	0.098	Low
24	Business, media and public service professionals	0.49	0.449	0.061	0	0	0.061	Low
31	Science, engineering and technology associate professionals	0.366	0.268	0.244	0	0.122	0.244	Low
32	Health and social care associate professionals	0.333	0.214	0.095	0.071	0.286	0.167	Low
33	Protective service occupations	0	0.25	0.083	0.033	0.633	0.117	Low
34	Culture, media and sports occupations	0.127	0.38	0.451	0	0.042	0.451	Med
35	Business and public service associate professionals	0	0.435	0.217	0	0.348	0.217	Low
41	Administrative occupations	0	0.121	0.879	0	0	0.879	High
42	Secretarial and related occupations	0	0.121	0.879	0	0	0.879	High
51	Skilled agricultural and related trades	0.096	0.231	0.154	0.077	0.442	0.231	Low
52	Skilled metal, electrical and electronic trades	0.05	0.05	0.1	0.05	0.75	0.15	Low
53	Skilled construction and building trades	0	0.12	0.08	0.12	0.68	0.2	Low
54	Textiles, printing and other skilled trades	0.074	0.111	0.185	0.259	0.37	0.444	Med
61	Caring personal service occupations	0	0.25	0.083	0.033	0.633	0.117	Low
62	Leisure, travel and related personal service occupations	0	0.095	0.857	0.048	0	0.905	High
71	Sales occupations	0	0.316	0.026	0.026	0.632	0.053	Low
72	Customer service occupations	0	0.095	0.857	0.048	0	0.905	High
81	Process, plant and machine operatives	0.068	0.205	0.295	0.273	0.159	0.568	Med
82	Transport and mobile machine drivers and operatives	0	0.04	0.14	0.74	0.08	0.88	High
91	Elementary trades and related occupations	0	0.316	0.026	0.026	0.632	0.053	Low
92	Elementary administration and service occupations	0	0.121	0.879	0	0	0.879	High

Source: Adapted from Perez-Silva & Campos-Gonzalez (2021) and Reijnders & de Vries (2018).

Now, we discuss how these routine intensity categories were distributed across industries in 2011 and 2021, considering that declines in Medium and High routine intensity jobs alongside increases in Low routine intensity would suggest a greater adoption of technological advancements since those declining jobs would be more exposed to automation. In this regard, Table 3 shows notable changes in employment structure across different routine intensity categories from 2011 to 2021. In the Agriculture sector, there was a 12%, 40%, and 27% decline in Low, Medium, and High routine-intensity jobs, respectively. Similarly, the Construction sector saw similar declines but a smaller decrease in all categories. Conversely, Manufacturing experienced a 5% increase in low routine intensity jobs, an 18% reduction in medium routine jobs, and a slight decrease of 1% in high routine jobs. Meanwhile, the Information and Communication sector recorded substantial growth in low routine jobs by 61%, a moderate 18% increase in medium routine jobs, and an 11% rise in high routine jobs. The rest of the industries also show a varying shift in employment structures, with distinct trends in the distribution of routine-intensity job categories.

Table 3: Workers (in thousands) in the UK workforce by routine intensity category and industry in 2011 and 2021.

Industry	Low			Medium			High		
	2011	2021	Change rate	2011	2021	Change rate	2011	2021	Change rate
Agriculture	215	188	-12%	44	26	-40%	98	72	-27%
Mining, energy, water	299	375	25%	61	52	-14%	137	144	5%
Manufacturing	1,406	1,478	5%	912	744	-18%	542	538	-1%
Construction	1,723	1,671	-3%	181	137	-24%	308	285	-8%
Wholesale and retail trade	2,864	2,625	-8%	209	193	-8%	961	956	-1%
Transport and storage	327	380	16%	47	42	-11%	1,077	1,080	0%
Accommodation and food service	369	389	6%	282	254	-10%	821	840	2%
Information and communication	748	1,206	61%	110	129	18%	202	223	11%
Financial and insurance activities	671	968	44%	14	18	29%	494	471	-5%
Real estate activities	203	308	52%	7	8	1%	89	102	15%
Professional, scientific and technical activities	1,214	1,958	61%	158	168	6%	485	581	20%
Administrative and support service activities	516	570	11%	40	35	-12%	743	798	7%
Public administration and defence; social security	978	1,417	45%	43	52	21%	854	853	0%
Education	2,326	2,651	14%	117	140	20%	678	651	-4%
Human health and social work activities	3,039	3,523	16%	91	85	-7%	837	858	3%
Other	581	722	24%	208	283	36%	756	742	-2%

Sources: Labour Force Survey and Census 2011, 2021 Microdata (Office for National Statistics, 2023a, 2023b, 2024)

Recalling the Agriculture results from Table 3, although the fall in Medium and High routine intensity jobs could indicate greater adoption of automation, the concurrent decrease in low routine jobs—contrary to the rest of the economy where low routine jobs are generally increasing—suggests a different dynamic. To illustrate, low-routine jobs have increased significantly in sectors like Information and communication and Financial Services. In contrast, the Medium and High routine intensity categories have shown more moderate changes or declines. This pattern in the Agriculture sector suggests unique sectoral trends that we analyse using our aggregated indicator of routine intensity at the industry level, *IndRI* (see Eq. 1 and related statements). *IndRI* represents the weighted sum of total employment by industry and provides deeper insights into these structural changes and their implications.

Table 4 presents the *IndRI* values for the UK's economic sectors for the years 2011 and 2021. The change rate between these years highlights the shifts in routine task intensity, which can indicate levels of automation adoption under our assumption that routine-intense jobs are more exposed to being automated or replaced by computer-based technologies. Our results suggest significant reductions in routine intensity in sectors such as Information and Communication (-17.86%), and Professional, Scientific, and Technical Activities (-14.71%). These decreases suggest a considerable shift away from routine tasks, both cognitive and manual, potentially indicating higher adoption rates of automation and advanced technologies in these industries. This kind of industry compounds high proportions of, among others, Science and technology professionals, which are characterised by high proportions of analytical and interactive non-routine tasks, as shown in Table 2.

In contrast, the Agriculture sector experienced a modest decline in routine intensity from an *IndRI* of 0.39 in 2011 to 0.36 in 2021, representing a change rate of -7.69%. While this reduction suggests some movement towards less routine-intensive work, it is slower than other sectors. Similarly, the Construction industry also saw a slight decrease in routine intensity, with the *IndRI* falling from 0.28 to 0.27, a change rate of -3.57%. This indicates minimal progress towards reducing routine tasks, suggesting, as in Agriculture, slower adoption of automation technologies. Meanwhile, the Accommodation and Food Services industry exhibited no change in its *IndRI*, remaining constant at 0.61 from 2011 to 2021, indicating no significant shift in routine task intensity. Overall, employment in these industries features high proportions of non-routine jobs, mainly manual, which are more challenging to automate (Autor, 2015; Autor et al., 2003). Manual tasks require situational flexibility, visual and language appreciation, and in-person interactions. We typically observe less skilled or unskilled occupations involving non-routine manual tasks (e.g., food preparation and serving, cleaning, fruit picking).

Overall, our results suggest that industries with more substantial reductions in routine intensity, such as Financial and Insurance Activities and Information and Communication, are likely advancing more rapidly in automation adoption compared to Agriculture, Construction, and Accommodation and Food Services. For Agriculture, this relative lag highlights the need for further technological integration to enhance productivity and efficiency.

Table 4: Estimated *IndRI* values for the UK's economic sectors for the years 2011 and 2021.

Industry	$IndRI$ 2011	$IndRI$ 2021	Change rate
Agriculture	0.39	0.36	-7.69%
Mining, energy, water	0.39	0.36	-8.49%
Manufacturing	0.39	0.38	-4.77%
Construction	0.28	0.27	-5.17%
Wholesale and retail trade	0.29	0.30	3.22%
Transport and storage	0.70	0.68	-2.76%
Accommodation and food service activities	0.61	0.61	0.07%
Information and communication	0.28	0.23	-16.72%
Financial and insurance activities	0.45	0.36	-20.11%
Real estate activities	0.37	0.33	-12.41%
Professional, scientific and technical activities	0.34	0.29	-14.35%
Administrative and support service activities	0.58	0.57	-0.69%
Public administration and defence	0.47	0.40	-15.03%
Education	0.29	0.27	-6.50%
Human health and social work activities	0.27	0.25	-6.09%
Other	0.54	0.50	-7.70%

Conclusion

Our findings confirm the current narrative that Agriculture 4.0 related technologies adoption is slow in the UK (DEFRA, 2022; Lowenberg-DeBoer, J. et al., 2022). The *IndRI* analysis from 2011 to 2021 reveals significant variations across different sectors in the UK. Some sectors such as Information and Communication, Financial and Insurance activities, and Professional, Scientific, and Technical activities have shown substantial reductions in routine intensity, indicating a rapid adoption of automation and advanced technologies. In contrast, Agriculture experienced only a modest decline in routine intensity, suggesting slower technological advancements associated with Agriculture 4.0. Similarly, sectors like Construction, and Accommodation and food services have seen minimal changes, indicating limited integration of new computer-based technologies.

The slower rate of decline in routine tasks in Agriculture than in other sectors suggests that this industry may not be advancing as quickly in adopting technologies such as automation and robotics, among others. This lag in technological integration could impact the sector's productivity and efficiency, making it less competitive compared to other rapidly evolving industries. Future research should focus on contrasting these findings with data from other sources, including more recent or specialised industry surveys, to validate the extent of technological adoption in Agriculture. Additionally, comparative studies across different countries could provide a broader perspective on how Agriculture 4.0 is being implemented globally and identify best practices that could accelerate the adoption of advanced technologies in agriculture. This cross-country analysis would help to understand the diverse factors influencing the pace of technological integration in agriculture, such as policy frameworks, investment levels, and workforce skills distribution.

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Impact of Agricultural Technology on Crops Diversification among the Farmers of Odisha, India

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Abstract

The implementation of agricultural technology can increase the income of farmers by boosting farm productivity. This may allow the farmers to go for crop diversification. This study examines this premise in relation to millets production, use of agricultural technology therein, and crop diversification by the farmers involved in millet production. Data on five hundred millet farmers in Koraput district of Odisha in India, have been collected to empirically test whether use of agricultural technology aids-in crop diversification. The study employs fractional heteroscedasticity probit model to ascertain the association between agricultural technology use and crop diversification. For the purpose of this study, a crop diversification index, and an agricultural technology intensity index has been framed. The study found that there is a statistically significant relationship between agricultural technology use and crop diversification. This is a noteworthy discovery given the growing importance of crop diversity as the farming class seeks higher income and countries seek agricultural self-sufficiency. After discovering this, the research proposes that governments worldwide should enhance agricultural technology adoption through appropriate policies.

Keywords

Agriculture Technology, Crop Diversification, Fractional Heteroscedasticity Probit, SDG, Climate Change.

Presenter Profile

I am Dr. Nihar Ranjan Jena, presently working as an Assistant Professor of Economics at the Indian Institute of Technology, Bhubaneswar. I hold a PhD in Economics from the University of Mumbai, a master's degree in economics from the University of Hyderabad, and a bachelor's degree in economics from Ravenshaw University, Odisha. My research interests include agricultural economics, rural development economics, and applied macroeconomics.

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Introduction

Climate change has created a significant issue for agricultural sectors. A big concern of this sector is sensitive to temperature and rainfall changes (Shakoor et al. 2011). Climate change refers to long-term changes in temperature and weather. Changes can be natural or human. Human activity is the principal cause of climate change (United Nations). Rising temperature and unpredictable weather pose a threat to traditional farming. Various climate shocks, such as droughts, floods, and cyclones, caused by climate change make farming less sustainable and less productive (Mohapatra et al. 2023). Also, changes in the temperature bring more weeds, bugs, and diseases, which makes it harder to handle crops and raises the cost of production (Chandio et al. 2020). Then, efficient use of agricultural technology allows rural households to grow crops with fewer inputs, lowering costs (Zhou and Ma 2022). Furthermore, agricultural mechanization has increased land productivity and food production for self-(Peng et al. 2022). The Indian agricultural sector experienced significant transformations and several modifications with the implementation of New Agricultural Technology in the mid-1960s. Since the 1990s, there has been a noticeable rise in the diversification of Indian agriculture (Ansari 2018). Crop diversification, which refers to growing more than one crop in an area, could also replace low-value agriculture products with high-value agriculture products. Diversifying the cropping pattern is being practiced by agricultural farmers to overcome crop production challenges, such as increased input costs, altering weather conditions, and increased demand for new products. These challenges are already posing obstacles to generate more income per acre from traditional crops. Thus, sustainability concerns have raised interest in crop diversification among agricultural farmers throughout the world (UN, Reno). Crop diversification can be justified as it increases economic benefits, environmental sustainability, nutritional security, social security, agronomic, and policy and development for agricultural farmers. Crop diversification could generate income stability by reducing parasites on mono-cropping, which may lead to price instability (Delgado and Siamwalla 2018; Makete et al. 2016). Moreover, crop diversification can open up new markets, which can increase high profitability for local products (Torres et al. 2021). Also, different crops have different uses of resources which allows for efficient use of land labor, and water (Malaiarasan et al. 2021).

Alletto et al. (2022) have established that the conventional way of farming is attributed to the degradation of natural resources. Crop diversification is considered an effective mechanism to increase environmental sustainability. Thus, the adoption of crop diversification as an alternative method to minimize environmental degradation. This method can be used to define local solutions to help environmental sustainability (Vanino et al. 2022). Further, primitive agriculture with mono-cropping and excessive use of chemical input has negatively affected belowground microbial composition, resulting in soil sickness and adverse effects on crop growth. Crop diversification has highlighted these problems more sustainably and ecologically, having seen future challenges (Wang et al. 2022; Walder et al. 2023; Baldwin-Kordick et al. 2022). The study of Mengistu et al. (2021) and Muthike et al. (2023) examined the effect of crop diversification on the food security of rural households of Sinana District, Oromia Regional State. They found that crop diversification had a positive effect on household food security. However, crop diversification was positively associated with household food security, many other factors such as education of HH, irrigation system, income, and livestock owned were found to be as more important in increasing household food security.

To face the increasing population pressure and changing consumption patterns, to increase the income of rural people and to expand the employment opportunities, agricultural diversification of the rural economy is necessary to lessen the burden on agriculture (Sonawane et al. 2022). However, with the development of secondary and tertiary sectors in developing countries, an increasing number of agricultural laborers have migrated from rural areas to urban in search of employment, which reduces livelihood vulnerabilities and may hinder the adoption of crop diversification strategies (Zhang et al. 2022). Additionally, studies found that the Ao Naga people, deeply rooted in their cultural heritage, are adeptly navigating the complexities of modernity by embracing sustainable practices that combine traditional wisdom with contemporary methods (Ozukum and Aswathy 2024). This study examines key aspects of their sustainable livelihood strategies, including organic farming, community-based tourism, revitalization of traditional crafts, and the adoption of renewable energy sources. Additionally, Feliciano (2019) observed that crop diversification is the most effective way of reducing poverty and losses of farmer's income. Crop diversification is a strategy that can help to achieve sustainable development goals (SDGs) such as no poverty, zero hunger, and climate action (Obisesan and Awolala 2021). Further, adopting modern technology in agriculture helps to address challenges to achieve the SDGs. Technology allows for cultivating multiple crops in different seasons, resulting in time saving, enhancing farm productivity, and reducing production costs (Sims and Kienzle 2016). Qurat-ul-ain Mastoi et al. (2014) identified how farmers in Malaysia are improving their economy through agricultural practices. Further, this study has stated that modern technology has played a significant role in the improvement of sustainable agriculture to ensure food security and environmental sustainability.

Odisha a state in the eastern part of India is also adversely affected by climate change. Therefore, farmers of this region have looked for some crops that are climate resilient like millet. Further, the state government has promoted a program to encourage millet production in the state to support the farmers and to reduce the adverse effects of climate change. However, merely dependence on millet production may not be beneficial. Therefore, farmers also have tried to diversify their agricultural activities to support their income. Crop diversification and the adoption of agricultural technology in millet production can solve the above problem in diverse weather conditions. Further, Input-based production, such as expanding land area, has a finite limit and may not be sustainable in the future. So, technological advancements, which have no bounds, offer a viable solution for the future. This means the use of agricultural technology in crop diversification particularly, may lead to an improvement in millet production and productivity. Therefore, there is a need for the advancement of agricultural technology in the diversification of crops in millet production.

This paper aims to find out the impact of agricultural technology on crop Diversification among the farmers of Odisha, in the context of the agricultural technology intensity index, crop diversification index, and climate change. Specifically, we seek to assess how agricultural technology diversifies agriculture. By doing so, the study addresses the following research question: How does adoption of agricultural technology impact crop diversification among the millet farmers of Odisha?

This document is organized as follows: Section 2 has a brief review of the related literature and the analytical framework derived from it; Section 3 describes the data and methods employed in the study; Section 4 explains the empirical results and discussion; and lastly, Section 5 presents the conclusion and policy implications.

Related Literature

There are number of approaches to sustainable agriculture. Of which, crop diversification is one of the most important approaches to sustainable agriculture. Crop diversification allows producers to minimize inputs, maximize output, and mitigate the risk because of environmental factors. It is an opportunity to enhance income growth, employment generation, food security, nutritional security, and sustainable agriculture (Barman et al. 2022). The study revealed that weeds are the major obstacles to crop production, which reduces production, productivity, and profitability (Sharma et al. 2021). Further, crop diversification could help to manage weeds in major crop production systems, under which technological advancement and ecological insights could be combined to manage weeds sustainably. Crop diversification can help to reduce weed density by inversely impacting weed growth. Moreover, diversified agriculture systems are more potent to climate change than mono-cropping systems that will help crops grow better. Nonetheless, there are few challenges to adopting crop diversification such as farm-level decisions, climate change, market conditions, and government policies.

Crop diversification will be simple when there is the presence of agricultural technology. Technological advancement can alter agriculture by reducing labour requirements, increasing productivity, and saving water. Often, agricultural technology reduces adverse impacts on soil, water, and improves the environmental sustainability of the production cycle. Also, have explored how they have shaped agriculture (Sassenrath et al. 2008). Agricultural technology helps to elevate the quality of soil such as moisture, soil nutrients, and PH level. With this information, farmers are able to choose a suitable crop for cultivation which leads to crop diversification (Fageria 2002; Francaviglia et al. 2022). The study of Abdul-Majid et al. (2024) looked into how farmers' well-being changed when they adopted new technologies. Specifically, looked into the ideas of technology adoption and well-being. Most of the papers showed that farmers' well-being was mostly judged by their income and output when they used new technologies. Vincent et al. (2011) carried out research to determine technical know-how among smallholder farmers using the Cobb- Douglas stochastic production function and the results found that output could be increased by 28 percent to 56 percent through better use of agricultural technology and available resources.

Agriculture is an important weapon to solve many problems of the rural households of third-world countries. Rural households solely parasites on agriculture to access food for their daily life. Researchers investigate the effect of crop diversification on food security and they found that crop diversification has a positive effect on the food security of rural households. However, several factors, the age of the HH, and distance to the market are inversely related to food security (Mengistu et al. 2021). Further, the growing population is grabbing natural resources from the future generation which could threaten their right to have clean air and nutritious food. These challenges can be solved by implementing some novel approaches such as climate-smart agriculture, organic farming, farm mechanization, precision agriculture, and crop diversification to safeguard agricultural sustainability (Muhie 2022). The study of Chavas et al. (2022) provided a comprehensive examination of yield risk, examining its changes over time and variations across different crops and regions for the economics of food security. The results reveal that the co-variability of yields diminishes as the distance between areas increases. This suggests that there are potential benefits to diversifying regionally to mitigate risk in the global food supply. It is seen that the impact of regional specialization on production is more significant than that of regional diversity. Brenya and Sampene (2023) found that the use of agricultural technology and the practice of crop diversity have shown to be an effective solution for addressing the pressing need for high-quality and nutritious food. Technology has enhanced the efficiency and efficacy of decision-making processes related to the financial, economic sustainability, and food security aspects of farming. Despite, the implementation of agricultural technology in low and middle-income nations (LMINs) is hindered by several barriers, including, high financial requirements, lack of technical expertise, and the impact of climate change. Besides, to address the growing population pressure and shifting consumer patterns, it is vital to diversify the rural economy. This will help increase the income of rural residents and create more employment possibilities, therefore reducing the reliance on agriculture. The use of diversification in the agriculture sector leads to the comprehensive advancement of a given region (Sonawane et al. 2022). Moreover, crop diversification mitigates the negative consequences of seasonality on farm income and peak labor demands, reduces the risk associated with erratic monsoon patterns, and leads to improved yields. Diversification of agriculture can be achieved in Boria a village in the Kesinga division of the Kalahandi district of Odisha by implementing cash-oriented cultivation. During a diagnostic visit, paddy was the sole crop that was cultivated during Kharif. The scientist encouraged the farmers to sift from high-water-required crops to low-water-required crops and from low-value crops to high-value crops, which can significantly impact their livelihoods and provide nutritional security (Tarai et al. 2015).

Implementing crop diversity has been noted as a strategy to address the gender disparity, which has the potential to increase agricultural output and improve overall well-being. The impact of crop diversification on improving dietary variety in the face of gender disparity in agricultural output among small-scale farmers in Nigeria. The findings demonstrated that crop diversity was positively influenced by factors such as farm income, education, farm size, and the utilization of inorganic fertilizer (Obisesan and Awolala 2021). Millet is becoming more popular again as people look for healthier and more environmentally friendly options, (Mundassery et al. 2024) discovered that in reaction to problems with global food security and climate change, many groups and institutions have pushed for more millet output and consumption by using new technologies and machines. Finally, Ansari (2018) investigated the share of gross domestic product has been falling even though 67% of marginal farmers dominated the agriculture sector. Crop diversification is the panacea for increasing GDP by shifting from food crops to noon- food crops mainly towards horticulture.

Research Gap

Climate change is a global problem and growing crops is challenging for the world. Meanwhile, millet is known for its climate-resilient, drought resilient, and pest-resistant properties. Moreover, millet offers numerous benefits to the consumers, producers, and ecosystem. Further, it found to be efficacious in augmenting production, productivity, and profitability in millet cultivation through agricultural technology and crop diversification. Therefore, both agricultural technology and crop diversification methods are essential for sustainable agriculture as the world wants to achieve SDGs. Nevertheless, the tremendous benefits of agricultural technology and crop diversification, there is a lack of research on the impact of agricultural technology on crop diversification among millet farmers and how both agricultural technology and crop diversification cope with the harmful effects of climate change.

Conceptualization

Climate change is adversely impacting agricultural production and productivity. On the other hand SDG 2 calls for ending hunger from the face of the world by 2030. Given these contrasting situations, and the attempt by countries to become agriculturally self-reliant, and the need to increase farmer's income, farmers can increase the use of agricultural technology. Use of agricultural technology, by way of increasing farm production and productivity, may enhance food security as well as farm income, prompting them to go for crop diversification. This relationship between agricultural technology use, high farm income, higher farm productivity and crop diversification may be illustrated as follows:

Moreover, agricultural technology adoption by the farmers may lead to better farm productivity which in turn may lead to higher income for the farming class. This may induce the farmers to go for multi cropping in a given period of time which not only fosters crop diversification but may also leads to further rise in farmer's income. When the farmers are able to achieve their food security from the cultivation lesser amount of land because of increased adoption of farm technology, there is an opportunity before them to diversify in favour of more remunerative crops.

Data and Methodology

The data for the impact of agricultural technology on crop diversification was collected through a survey of households conducted during December 2023 and January 2024 in Odisha. The study has been conducted based on the primary data. For primary data collection, one district of Odisha has been taken based on the intensity of millet cultivation. Purposefully, Koraput district was chosen as the sample area for the collection of primary data as the population of millet farmers is highest in this district among all the 30 districts of Odisha. Farmers prefer growing finger millet (ragi) and little millet (gurji) as it is leading millet producing district, with a fertile landscape. Simple random and multi-stage sampling methods have been applied to select the millet farmers for the collection of raw data. From Koraput district, two blocks, Nandapur and Semiliguda have been taken randomly. From the Nandapur block, eight (8) villages, namely Sarabati, Vitenguda, Hadaput, Nalachua, Kharagpur, Khujel, Muduliput and Marada have been taken for sample data collection. On the other hand, from Semiliguda block, three (03) villages, namely Majhiput, Parajamuthai and K. Sunabeda have been taken for sample data collection. A total of five hundred (500) samples were collected to know the agriculture technology intensity index and crop diversification index of farm mechanization in agricultural cultivation. Of which, 278 households were taken from Nandapur and the remaining 222 households were taken from Semiliguda block of Koraput district. More samples have been taken from the Nandapur block than the Semiliguda block based on population size as the size of population of the former is higher than the population of the later. The collected data are presented through descriptive statistics. Further, the study employs the fractional heteroscedasticity probit regression model.

Among the explanatory variables, CDI is calculated by taking simple average of six different crops being cultivated by the farmers during the last year. In millet cultivation, the Agriculture Technology Intensity Index (ATII) is one parameter that impacts crop diversification. We use the Agriculture Technology Intensity Index as an indicator to gauge the level of technological development and deployment in agriculture production. It takes into account mechanisms such as mechanization, training and education, irrigation facilities, the application of fertilizers and pesticides, and a high-yielding variety of seeds. This index will permit a comparative assessment of the use of technology in any given agricultural technique for different crops across different periods. Operational holdings of the farmers is calculated by adding leased-in land to the farmer's owned land net of leased-out land. Intensity of institutional barriers is calculated by assessing the ease of farmer's access to various agricultural schemes such as Odisha Millet Mission (OMM), Rashtriya Krishi Vikas Yojana (RKVY), Krushak Assistance for Livelihood and Income Augmentation (KALIA), Prime Minister Fasal Bima Yojana (PM-FBY), Prime Minister Krishak Samman Nidhi (PM-Kishan), and Kisan Credit Card (KCC).

A fractional heteroscedasticity probit model is a specialized regression model used to analyze data with a fractional dependent variable, where the variability of the errors is not constant across different levels of the independent variables. It combines elements of probit modeling with techniques to address heteroscedasticity, providing a flexible framework for analyzing proportional data with varying levels of uncertainty. The fractional heteroscedasticity probit model can be presented in the following functional form:

Latent Variable Representation:

$y_i^* = X_i\beta + \epsilon_i$

where:

y_i^* is the latent continuous variable.

X_i is a vector of explanatory variables for the *i*-th observation.

β is a vector of coefficients.

ϵ_i is the error term.

Heteroscedasticity in the Error Term:

The variance of the error term is allowed to vary with covariates Z_i:

$\epsilon_i \sim N(0, \sigma_i^2)$

$\sigma_i^2 = \exp(Z_i\gamma)$

Where:

Z_i is a vector of variables that determine the heteroscedasticity (could be different from X_i or the same).

γ is a vector of coefficients.

Probability of the Binary Outcome:

The probability that y_i=1 is given by:

$P(y_i=1 \mid X_i, Z_i) = P(y_i^* > 0 \mid X_i, Z_i) = P(X_i\beta + \epsilon_i>0) = P(\epsilon_i>-X_i\beta)P$

Given that $\epsilon_i \sim N(0, \sigma_i^2)$, the above probability can be expressed using the cumulative distribution function (CDF) of the normal distribution:

$P(y_i=1|X_i,Z_i)=\Phi(X_i\beta / \sigma_i)=\Phi(X_i\beta / \exp(Z_{i\gamma} / 2))$

where $\Phi(\cdot)$ denotes the CDF of the standard normal distribution.

Based on our study objectives, and the variables under this study, we intend to estimate the following equations in order to ascertain the relationship between crop diversification and agricultural technology use intensity.

Crop Diversification = f (Agricultural Technology Intensity Index, Family Size (of the respondent), Years of Education, Age, Gender, Total Income, Arable Irrigated, Land, Operational Holdings, Intensity of Institutional Barriers)

The mathematical form of the above functional relationship can be presented as under:

$CDI = \alpha + \beta_1 ATII + \beta_2 F + \beta_3 YoE + \beta_4 A + \beta_5 G + \beta_6 Y + \beta_7 L + \beta_8 OH + \beta_9 IIB + u_i$

Where:

ATII: Agricultural Technology Intensity Index; F: Family Size; YoE: Years of Education; A: Age; G: Gender; Y: Total Income; L: Arable Irrigated Land; OH: Operational Holdings; IIB: Intensity of Institutional Barriers.

Results and Discussion

Before, we discuss the regression results from our quantitative analysis, let us throw some lights on the nature of the data by glancing through the descriptive statistics detailed in Table 1.

Table 1: Descriptive Statistic

Variable	Obs	Mean	Std. Dev.	Min	Max
Family Size	500	4.41	1.76	1	10
Years of Education	500	3.98	4.2	0	15
Age	500	41.65	12.69	16	70
Gender	500	0.93	.24	0	1
Total Income	500	38731.06	31082.72	0	400000
Arable land Irrigated	500	0.84	1.23	0	15
Operational holding	500	2.06	1.46	.01	15
CDI	500	0.83	.007	.66	.83
Intensity of Institutional barrier	500	0.40	.081	.16	.56
ATII	500	0.13	.05	.07	.23

Source: Author's calculations

From the table above on descriptive statistics, the dataset consists of 500 observations, encompassing a range of socio-economic and demographic variables. The average family size is 4.41 members with a standard deviation of 1.76, ranging from a minimum of 1 to a maximum of 10 members. The years of education among the participants vary widely, with a mean of 3.98 years and a standard deviation of 4.2 years, spanning from no formal education to a maximum of 15 years of education.

The average age of the participants is 41.65 years, with a standard deviation of 12.69 years, and an age range from 16 to 70 years. Gender distribution is highly skewed, with a mean of 0.93 and a standard deviation of 0.24, indicating a predominance of one gender (likely male) in the sample.

The total income of the households shows significant variability, with a mean income of 38,731.06 currency units and a standard deviation of 31,082.72, ranging from no income to a maximum of 400,000 currency units. Arable land irrigated averages at 0.84 hectares with a standard deviation of 1.23, ranging from 0 to 15 hectares. Operational holdings have a mean size of 2.06 hectares and a standard deviation of 1.46, with the smallest holding being 0.01 hectares and the largest 15 hectares.

The Crop Diversification Index (CDI) has a mean value of 0.83 and a very low standard deviation of 0.007, indicating minor variability with values ranging from 0.66 to 0.83. The intensity of institutional barriers has a mean of 0.40 and a standard deviation of 0.081, ranging from 0.16 to 0.56. Finally, the Agricultural Technology Innovation Index (ATII) averages at 0.13 with a standard deviation of 0.05, spanning from 0.07 to 0.23. These statistics provide a comprehensive overview of the socio-economic and demographic characteristics of the sample.

We now discuss the regression results from our fractional heteroscedasticity probit regression model as given in Table 2.

Table 2: Regression Results

Variable (CDI)	Coefficient	Std. error	P- value
Crop Diversification Intensity (CDI)			
ATII	0.707	0.361	0.050
Family Size	0.030	0.013	0.024
Years of Education	0.001	0.001	0.257
Age	-0.002	0.001	0.049
Gender	-0.065	0.037	0.083
Total Income	0.000	0.000	0.060
Arable land Irrigated	0.013	0.007	0.065
Operational holding	-0.004	0.004	0.267
Intensity of Institutional barriers	-0.402	0.215	0.062
Constant	0.967	0.002	0.000
ln sigma			
ATII	0.736	0.393	0.061
Family Size	0.031	0.014	0.030
Years of Education	0.001	0.001	0.225
Age	-0.002	0.001	0.068
Gender	-0.065	0.040	0.098
Total Income	0.000	0.000	0.050
Arable land Irrigated	0.014	0.008	0.071
Operational holding	-0.005	0.004	0.270
Intensity of Institutional barrier	-0.416	0.237	0.079

Table 1 explains the factors that influence crop diversification intensity (CDI). The ATII has a positive coefficient (0.707), suggesting that as the agriculture technology intensity index increases, the intensity of crop diversification also increases at a five percent level of significance (Sharma et al. 2017). As a household's family size grows, so does the intensity of crop diversification in agriculture (Basantaray et al. 2024). Family size has a positive coefficient (0.030), indicating that as the family size of a household increases, the intensity of crop diversification among farmers increases from single crop to multiple cropping systems, as evidenced at a five percent level of significance. Further, the age of the household is another parameter that impacts crop diversification in agriculture. The parameter age has a negative coefficient (-0.002), indicating that as the HH age increases, the intensity of crop diversification will decrease at a five percent level of significance. Agriculture is the backbone of the rural economy because 67 percent of marginal farmers rely on it for their livelihood. Whether the head of the household is male or female, gender plays a crucial role in Indian agriculture, bearing an equal share of the burden for agricultural activities. However, the parameter gender has a negative coefficient (-0.065), indicating that as the male (compared to the female) increases, the intensity of crop diversification in agriculture decreases. Furthermore, arable, irrigated land is a prerequisite for increasing agricultural production to meet the needs of the world's growing population. To achieve this goal, the soil's indestructible powers and water availability must be considered (Schiefer et al. 2015). Crop diversification enhances the efficiency of land use and crop output by enhancing the physical and chemical qualities of soil (Barman et al. 2022). Arable irrigated land exhibits a positive coefficient (0.013), indicating that an increase in the size of arable irrigated land leads to a ten percent increase in crop diversification intensity in agriculture (Micheni et al. 2024). Despite the benefits of both state and central government schemes for agriculture, the adoption of different farm mechanizations in millet farming is hindered by institutional barriers, which prevent farmers from reaping these benefits. Similarly, institutional barriers act as impediments to crop diversification within the study area. The institutional barrier intensity (IIB) has a negative coefficient (-0.402), indicating that the intensity of crop diversification will decrease at the ten percent level of significance.

On the other hand, the result explains how the error term's variance changes with the explanatory variables and the model's coefficient of variance. Agricultural technology intensity is one of the most important parameters that impacts crop diversification in millet cultivation as well as other crops. ATII has a positive coefficient of 0.736, which means that for every unit increase in ATII, the variance of the error term goes up by 0.736. This means that at a ten percent level of significance, higher agricultural technology intensity is linked to more variability in crop diversification evidence. Further, crop diversification is also dependent upon family size, indicating that a one-unit increase in family size increases the variability of crop diversification by 0.031, resulting in a larger family size being associated with more variability in crop diversification at the five percent level of significance. At a ten percent level of significance, the parameter age exhibits a negative coefficient, demonstrating that an increase in the household's year leads to a -0.002 decrease in crop diversification. This implies that a variable age experiences less variability with crop diversification. Gender (whether the head of the household is male or female) plays a crucial role in decision-making and has an equal share of the burden for agricultural activities. The parameter gender has a negative coefficient, indicating that an increase in males (as compared to females) decreases the variability of crop diversification by -0.065, which shows a negative association between gender and crop diversification. Moreover, the coefficient for arable irrigated land is positive (0.014), indicating that an increase of one acre in irrigated land increases the variability of crop diversification by 0.014. This suggests that larger arable irrigated land sizes are associated with higher levels of variability, a finding supported at a ten percent significance level. Furthermore, operational holding, defined as the total land leased-out plus the land leased within the land, exhibits a negative coefficient. This implies that an increase in the size of the operational land holding leads to a decrease in crop diversification variability, with no evidence of variability present. Finally, the intensity of the institutional barrier has a negative coefficient. This means that at a ten percent level of significance, an increase in the intensity of the institutional barrier lowers the difference in crop diversification by -0.416.

Conclusion and Policy Implications

The implementation of agricultural technology has the ability to increase the productivity of farmers, which in turn has the effect of raising the revenue that farmers earn. There is a possibility that this will make it possible for him to experiment with agricultural diversification. This assumption will be analysed in relation to the production of millets, the application of agricultural technology during the process, and the diversification of crops by farmers who engage in such manufacture. The objective of this study is to investigate these aspects. In order to accomplish the objectives of this study, primary data were gathered from a sample size of five hundred millet farmers who were situated in the Koraput district of Odisha, India. This particular district is widely regarded as being among the most densely inhabited millet-producing locations in the entire globe. Millet has emerged as one of humanity's greatest bets against the never-ending pursuit of global food security, a challenge that is growing more difficult with each passing day as a result of the challenges encountered by climate change. Millet is a cereal grain that is typically known for its high nutritional value. As a result of this, the context is extremely important. Millet is not only resistant to the effects of climate change, but it is also a nutrient-dense powerhouse that is resistant to both drought and pest populations. In addition, millet is immune to the risks associated with climate change. Millet is positioned to become one of the ways for the global community to attain sustainable development goals by the year 2030 as a result of these remarkable features that are found within a single cereal class. This is because millet is a grain that contains all of these traits. The outcomes of this study indicate that the implementation of farming technology by farmers leads to a significant rise in the variety of crops that are grown during growing seasons. In addition to attaining food security through suitable output, farmers who are engaged in millet production are also able to produce a variety of crops throughout the year, which enables them to achieve crop diversity. Furthermore, millet cultivation allows farmers to achieve food security. This revelation is of the utmost significance since it provides evidence that these farmers are capable of achieving an adequate level of food security. In view of the fact that the farming class is working toward improving its income and countries are working toward achieving self-sufficiency in agricultural production, this is a significant revelation especially when taking into consideration the growing relevance of crop diversity. When this was found out, the research advises that policymakers all over the world should encourage the use of agricultural technology by means of appropriate legislation. This is because of the fact that this was revealed.

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Keynote: Adoption of robotics and AI in the agri-food system

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Presenter Profile

Simon has been responsible for founding and developing the Lincoln Institute of Agri Food Technology (LIAT), now recognised as "world leading" within the 2021 BEIS Innovation Strategy, Creating the Future. His group have helped pioneer the development of advanced robotic systems, machine learning, artificial intelligence and digital systems for UK agriculture. In 2021, he co-chaired the DEFRA Automation and Robotics Review with former Secretary of State George Eustice. For his contribution to the sector, he was awarded the 2022 RASE Science and Technology Award.

How do English farmers respond to Brexit agricultural policy change?

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Abstract

The UK's withdrawal from the EU provided the UK government opportunity to develop a sustainable agricultural policy to tie the payment more to the delivery of public goods such as biodiversity, soil health, water quality and animal welfare. However, the shift may impact farm profitability and has created uncertainty for UK farmers, especially those heavily reliant on direct payments. This study aimed to understand how English farmers respond to such agricultural policy changes.

This study uses a nationally representative dataset with a sample size of 1769 English farmers. The dataset comprised responses to both structured questionnaire surveys and semi-structured interviews to provide insights into the adjustment strategies and action plans that farmers might use to adapt their farm businesses to the proposed changes in agricultural policy post-Brexit. Each interview produced a summary of action plans with a 2,000-character limit, which was analysed using IBM advanced linguistic technologies and Natural Language Processing (NLP).

The findings show that farmers having higher confidence in farming future and changes were more likely to be younger, full-time, or in cereal or dairy farming sectors. Younger and full-time farmers also showed higher level of business management skills. Thematic content analysis of actions planned by the farmers showed that farmers' adjustment strategies include business diversification, increasing profitability by either enhancing productivity or focusing more on specialisation. The study findings also reveal that majority of the farmers are prepared to implement actions to enhance their business resilience and enrol into environmental schemes with Countryside Stewardship being the most commonly adopted.

Further analysis showed three types of farmers in response to the changes: forward-facing adventurers, conservative performers and adaptable pragmatist. Implications of how policies and support can be tailored to each type of farmers will be discussed.

Keywords

Adaptation strategies; Adjustment strategies; Agri-Environmental Schemes; Post-Brexit agricultural policy change; English Farmers.

Presenter Profile

Dr Iona Huang is a Senior Lecturer in the Department of Food, Land & Agribusiness Management at Harper Adams University. Dr Huang's research features the application of circular economy principles within the agri-food sector and agency theory in the governance of supply chain. Her recent engagements include projects funded by AHDB and DEFRA, addressing sustainable farming incentives, farm resilience, landscape recovery, and innovations in protected environment agriculture. Currently, her work focuses on the management of excess food supply and the impact of food loss and waste, and assessing the sustainable value of farming practices and paludiculture. Additionally, Dr Huang contributes as an expert to the ISO working group, aiding in the development of the ISO20001 management standard on minimising food loss and waste in the food supply chain.

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What Farmers Think About Lab-Grown Meat in the UK: across sectional study

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Abstract

Lab-grown meat (LGM) is an evolving meat production technology which has increasingly attracted attention as both a solution to food security as well as a likely threat to established livestock systems. Much of the evolving literature has investigated the extent that LGM would be accepted by consumers since its early proof of concept stage to more recently bringing product to market. Moreover, initial research investigated consumers from a European or North American perspective. Yet, more recently there have been many examples of similar consumer research on preference and willingness to adopt LGM from Asia, the Middle East and Africa. Despite the bulk of existing literature being consumers, there is still a gap in the literature on the extent farmers might consider such a technology. A few studies have delved into farmers' perception and the likelihood they might accept or reject the implementation of LGM in the UK market. Therefore, a research gap has been identified as it is deemed important to explore how the widespread introduction of LGM might impact the livelihoods of farmers and the factors driving or hindering the adoption of LGM. As for methodology, a cross sectional study was chosen and data was collected from those in the farming sector. Poultry farmers who are part of a large poultry integration company were targeted first as well as other farmers in both livestock and arable activities. Data was collected using an on-line survey platform JISC containing open and closed questions. The results were analysed using SPSS and the statistical analysis indicated that UK farmers had an overall negative attitude towards LGM due to (1) The impact such a technology could have to their livelihoods; (2) The threat LGM could have to UK culture, public health, and ethical values; and (3) One third of the respondents, predominantly UK farmers, would protest against the implementation of LGM in the UK market. As a result, UK livestock farmers could strongly resist adopting and potentially prevent LGM entering the UK market. Nonetheless, the results also indicate that most farmers were unwilling to change farming activity or produce LGM; not only because they disagreed with the concept, but also because of a lack of resources and knowledge to do so. Interestingly, the demographic profiling of the respondents did not correlate to the farmers attitudes towards LGM technology. Whilst younger farmers in general were less likely to accept LGM in the UK market, poultry farmers were found to have a more positive response to LGM than those of other farming activities. Overall, the respondents indicated that they lacked knowledge, resources and even passion to embrace with the opportunities the new LGM technology might unfold.

Presenter Profile

Luis De Aguiar is a Senior Lecturer in Food Marketing and Sustainability in the Harper Adams Business School at Harper Adams University. I have worked in the private and public sectors prior to becoming a full time academic. I have an extensive professional experience which has led me to get involved in teaching, training and consultancy in various countries including China, France, Israel, Brazil, Saudi Arabia, Viet Nam, Peru, Laos, Venezuela to mention some.

SME Agri-Businesses Barriers to Sustainability: A West Midlands Perspective

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Abstract

With the current demands to improve Carbon dioxide (CO2) emissions, it has become imperative for organisations to embrace the NetZero concept. Although it has been evident that large companies contribute considerably to emissions, however, SMEs employ half of the world's population. This emphasises the vital role and responsibility hanging on SMEs in mitigating Climate change. SMEs as individual organisations may seem to have a lesser impact, but their collective emission impact may be far-reaching when viewed as a large group of organisations (Blundel, 2021). It has been observed that SMEs have fallen short of either not understanding NetZero intentions or the need for skills and expertise to translate their sustainability initiatives into concrete results (Consequence, 2024). There have been some Sustainability Support Schemes for SME Agri-businesses to overcome these challenges SMEs face in the West Midlands of England. However, Some SMEs have not yet adopted any form of sustainability or taken advantage of the available Sustainability schemes. Hence, the purpose of this work is to examine the barriers deterring SMEs from engaging or partially engaging with these schemes. And to propose ways to better support SMEs. A semi-structured interview was adopted engaging five interviewees who are either business engagement managers or Knowledge exchange researchers or have been engaged in both roles at some point over the past six years. The result showed that SMEs struggle mostly with time, resources, and skills to engage fully with the schemes. It is suggested schemes should emphasise quality over quantity, devoting more time to each SME, more follow-up is needed to ensure adaptation, and there is also the need to speak the SME language.

Keywords: Sustainability Initiatives, Agri-Tech, Small and Medium Enterprise (SME)

Presenter Profile

Maria Aina is a Senior lecturer in Logistics and Supply Chain Management at Harper Adams University. She previously worked as a lecturer at the University of Northampton, as a Senior Associate Teacher at the University of Bristol, and as a Research Associate/Fellow at Aston University. Her research interests are in Sustainable supply chain management, Agribusinesses, Project Management, the Circular Economy, Business Strategy, Entrepreneurship, and Business Analytics.

Introduction

In 2019, the West Midlands region had a population of around 6 million people and 480,000 businesses in the private sector (both registered and unregistered). Micro-firms and SMEs are the backbones of the West Midlands' economy, together comprising 99.9% of the total enterprises in the West Midlands, creating 58% of the employment and 44% of the turnover throughout the last ten years (Yoruk and Gilman, 2021). On Friday, 28 May 2021, Prime Minister Boris and Business and Energy Secretary Kwasi Kwarteng called on every small business in the UK to take small, practical steps to cut their emissions as part of the UK's journey to net zero by 2050 (Gov.UK, 2024). However, before and after the May 2021 announcement, there have been Sustainability Support Schemes for SME Agri-businesses in the West Midlands, a few of which are the Agri-tech Growth and Resources for Innovation, Sustaining Shropshire, Energy and Bioproducts Research Institute (Businessclimatehub, 2024). These schemes started prior to Brexit; the European Regional Development Fund (ERDF) funded and supported various small-scale programmes in the West Midlands, England, to achieve the reduction in emissions by providing information, advice and financial incentives for SMEs (Khosravi et al., 2023). Although the ERDF support schemes stopped in the UK after Brexit, other streams of funding and support, such as the innovative UK and other government bodies, sprung up post-Brexit. However, despite the availability of these schemes, several barriers have hindered some businesses from engaging or fully engaging with the sustainability schemes.

The aim of this research is to examine the barriers confronting SMEs in embracing available sustainable intervention schemes and explore ways to encourage them to engage more effectively with them.

The outlined objectives to satisfy this aim are to:

- Ascertain how the interventions have supported SMEs in becoming sustainable
- Examine the barriers facing West Midlands SMEs from engaging with sustainability schemes
- Suggest insights that could encourage SMEs to better with Agri-tech sustainability schemes

NatWest Group (2022) In 2021, the British Business Bank estimated that UK SMEs accounted for about 43-53% of the UK business emissions. NatWest Group research also revealed that 87% of UK SMEs are unaware of their business's total carbon emissions. This reveals the need for more SME support and presents a gap in the SMEs' engagement with available sustainability schemes.

Therefore, the research question is, 'Despite the available schemes, what are the factors debarring SMEs from adopting decarbonisation strategies or engaging with the schemes?'

This research will explore the barriers that prevent SMEs from decarbonising across the West Midlands, UK, including Birmingham, Coventry, the Marches region, and Shropshire, and provide recommendations on how to overcome these barriers. The answers to the above questions would be useful for practitioners and policymakers to better understand the sustainability challenges faced by SMEs and, in turn, put in place adequate, precise, and tailored plans to support them further.

Methods

A qualitative research and exploratory approach were employed to gain a more comprehensive understanding of the barriers faced by SMEs to engage with the sustainability schemes and drivers that could encourage better SME engagement (Bougie and Sekaran, 2019; Saunders et al., 2019). To this end, five in-depth interviews were conducted with interviewees via video Teams calls. The questions were divided into two main parts; the first is to explore how the scheme has supported SMEs within the West Midlands region, while the second part gets depths into why SMEs have not yet or fully engaged in being sustainable and their perspective of what could be done to encourage more commitment towards sustainability. Interviewees are Business Engagement Managers and/or Knowledge Exchange Researchers for Sustainability Support Schemes for SMEs in the West Midlands to assess how their interventions have supported SMEs in becoming sustainable. The interviewees are Business Engagement Managers and Knowledge exchange researchers who have worked on at least two of the Sustainability Support Schemes for SMEs in the West Midlands within the last five years and have at least six years of experience in the role, working closely with between (150 -500) SMEs in the West Midlands.

Results

Available Support for SMEs

For SMEs, the expectations and commitment to achieving NetZero spans across identifying the near-term target which could involve rapidly eliminating emissions through adopting carbon reduction opportunities; reducing scopes 1, 2, and 3; committing to halving emissions by 2030; and achieving near-zero GHG emissions by 2050 (Consequence, 2024). All the interviewees mentioned that they assist SMEs in decarbonisation, sustainability, or moving towards NetZero. The support ranged from carbon audits, carbon calculations, pointers to available funding, and, most significantly, suggesting appropriate technology to support the efficiency and sustainability of the Supply Chain.

Interviewee 4: We provide Agri-food processes and technology to support SMEs in the West Midlands…. supporting the food process, new products, lifecycle, and shelf labelling but not the legal aspect.

Interviewee 5: We support by suggesting the best-suited technology for the agribusinesses

Barriers to engaging with the Intervention Schemes

Researchers identified barriers such as resource constraints (Trianni and Cagno, 2012), lack of specialist knowledge and technical skills (Fresner et al., 2017), short-term tenancies (Fawcett and Hampton, 2020), and financial constraints as the principal barriers (Andrews and Johnson, 2016). However, this work also identified barriers such as demotivation, Time and Technology challenges, and scheme targets that promote Quantity over Quality.

Demotivation

Interviewee 1: The speed of the academic nature is not fast-paced enough for SMEs. We focus on the fine details. SMEs have limited resources (people and money), so they struggle on a day today. Their goal is to make money (long-term to see productive outcomes). The micro-SMEs really struggle. They know the interventions are good, but they cannot spare time to engage.

Interviewee 2: Some get interested initially but aren't aware of how things are done at the university because they aren't used to the university bureaucracy. So, they may not engage again because they are disappointed.

Based on these responses, schemes overseen by universities need to tell SMEs more about what to expect to prepare their minds and give them a heads-up on how things work with the scheme.

Time and Technology challenges

Interviewee 1: Some of the technologies proposed are not practical. In the short term, it isn't achievable for SMEs, and in the long term (by the time the organisation is ready, the tech might have changed).

Interviewee 2: It's not speaking SME language; it's communicating in the way they understand. Time – critical to the operations required on a day. It could take someone off their day-to-day. For example, the Master Classes – I can't be available for two days

Interviewee 3: Some finish the intervention process with us, but it's not certain that they implement the suggestions we give. For example, an organisation we worked with and trained on ERP software but upon follow-up they haven't gotten time to implement and some struggle with the money aspect.

Quantity emphasis over Quality

Interviewee 4: Our funding scheme speculated 100 outputs over two years, and we have to give each SME only 12 hours of support—the support is short.

From these responses, it is suggested that the technology interventions proposed should be suitable for SMEs, considering the organisations' available resources and technology implementation time. Sustainability Schemes should emphasise quality over quantity. Training should be provided to support the suggested technology, and a follow-up programme should be conducted afterwards to ensure its implementation.

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Understanding sustainable value of regenerative livestock farming and on-farm community engagement - a case study of Fordhall Farm

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Abstract

The livestock sector faces multiple challenges: growing demand, stricter welfare standards, and environmental pressures. With livestock contributing 14.5% of global GHG emissions and policy changes like the phasing out of England's Basic Payment Scheme, farmers must adapt for sustainability and financial viability. Pasture-based livestock systems offer potential benefits beyond food production, including cultural preservation, biodiversity enhancement, and rural vitality. However, comprehensive assessment of their multidimensional value is lacking. This study evaluates a case farm that combines pasture-based regenerative livestock farming with community activities and tourism, aiming to quantify its diverse sustainable values and understand what the trade-offs might be and how synergies are created. Such assessment is crucial for informed decision-making in agricultural policy and practice towards more sustainable farming systems.

The project develops a comprehensive sustainability assessment framework, tailored to the farm's diverse activities and unique ownership structure. It involves co-designing data collection methods, including financial records, activity logs, carbon audits, soil testing, and biodiversity surveys combined with triangulation for social dimensions using observations, interviews, and focus groups. Monetary valuation of non-market goods used various methods: cost-based, hedonic pricing, willingness to pay, and value transfer.

True Cost Accounting (TCA), an approach to understanding the positive and negative impacts of any production systems on the natural environment, society, and the economy (Sandhu et al., 2021) was applied to assess the economic, environmental, and social values. The study's initial findings include:

- Mapping of farming and diversification activities against four outcome categories: economic, environmental, social, and human capitals.
- Identification and explanation of monetary value sources.
- Discussion of deflators such as deadweight and substitution effects, which refine the valuation process.
- Presentation of the final sustainable valuation results for outcomes generated by the case farm.

This comprehensive analysis provides a holistic view of the farm's contributions and impacts, offering valuable insights for sustainable agricultural practices and policy development.

Presenter Profile

Iona Yuelu Huang is a senior lecturer at Harper Adams Business School, Harper Adams University. Her primary research interest is in agri-food business decision making and behaviour change. This includes food loss and waste management, sustainable land use and food supply and agri-tech innovation adoption. She has been a member of several research teams, including AgroCycle (a Horizon 2020 project), Paludiculture Innovation Project (funded by Natural England), and Park Royal PBIAA Net-Zero Food Supply Chains project (funded by EPSRC).

Agricultural productivity measurement incorporating environmental and non-market indicators: A systematic review

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Abstract

Agricultural Total Factor Productivity (ATFP) estimates have always focused on traditional inputs (land, labour, capital) and output summarized in monetary values when measuring productivity efficiency. However, increasing public awareness about environmental, social and ethical inputs and outputs highlights the need for a shift in research focus to consider non-market indicators into ATFP measurement. Through a systematic literature review, this study aims to analyse existing literature to establish a robust theoretical framework for enhancing farm productivity measurement and improved agricultural research policy. The search for relevant evidence sources was performed on nine databases and generated a total of 8663 results. Following TAK (Title-Abstract-Keyword) and Full Text screening in line with pre-determined inclusion and exclusion criteria, critical analysis was conducted on the final sample of 60 articles. The analysis indicated that the majority of the studies utilised annual panel data, while the most popular methods in measuring ATFP incorporating environmental and non-market indicators are Data Envelopment Analysis, Stochastic Frontier Analysis and the Malmquist Productivity Index. The ways that researchers have chosen to incorporate non-traditional factors in ATFP analysis is as undesirable output, stochastic inputs, or environmental indexes. In addition, the systematic literature review showed that past research has focused on incorporating environmental factors such as weather, carbon and greenhouse gas emissions, and soil pollution in productivity measurement, indicating a research gap for studies that incorporate social factors and animal welfare in ATFP. Overall, findings suggest that measured productivity growth is negatively affected when incorporating non-conventional factors in ATFP measurement. Therefore, it is essential to consider environmental and non-market indicators when assessing ATFP to get a more accurate indication of agricultural productivity efficiency.

Keywords

Agricultural TFP, productivity measurement, environment, non-market indicators

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Keynote: Innovate and Democratise: A Pathway to Increased Adoption of Agricultural Technology?

Professor Dimitrios S. Paraforos

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Presenter Profile

Dimitrios S. Paraforos grew up on a farm in northern Greece. He completed a bachelor's degree in automation engineering and a master's degree in agricultural engineering. After several years in industry, he moved to the University of Hohenheim (Germany), where he obtained his Ph.D. in 2016 and his Habilitation in Agricultural Engineering in 2020. In 2018, he received the Baden-Württemberg Certificate for University Didactics and in 2020, he was awarded the GIL Prize for his habilitation thesis.

Since April 2023, he has been Professor of Technology in the Cultivation of Specialty Crops at Geisenheim University. He is also Associate Editor of Computers and Electronics in Agriculture and Smart Agricultural Technology (both published by Elsevier). He has been involved in more than 20 European and national research projects in the field of digitisation of agriculture and technology transfer.

He is currently coordinating two BMEL-funded projects, DIWAKOPTER and Oenotrace, dealing with the implementation and traceability of sustainable cultivation practices in specialty crops. In 2024, he was awarded the LOEWE Transfer Professorship by the State of Hesse, with funding of one million euros. His research interests include the automation of agricultural machinery, unmanned ground and air vehicles, and distributed and resilient digital farming systems.

Food and Crop Management on LinkedIn: A Topic Analysis

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Extended Abstract

In this work, we utilize the Latent Dirichlet Allocation (LDA) methodology to scrutinize the key aspects and dimensions of crop and food management companies, as they engage on LinkedIn. To do so, we have utilized the information derived from the LinkedIn profiles of these companies. The LDA analysis reveals distinct themes in crop and food management, particularly, crop management emphasizes advancing agricultural practices through technology and research (Topic 1) and enhancing sustainability with a focus on farmers and data-driven methods (Topic 2). In contrast, food management centers on food safety, quality control, and regulatory compliance (Topic 1), also addressing business aspects like marketing and customer experience (Topic 2). While crop management focuses on improving production and sustainability, food management balances high safety standards with business performance. Both fields highlight the importance of quality and technological advancements but address different sector-specific challenges and priorities.

Introduction

Agriculture is one of the most important sectors of the economy, with the sustainability of every country being based on this sector's performance (Khan et al., 2022). Crop and food management systems are closely related with several implications for both (Long et al., 2024).

Consequently, analyzing and comparing companies' descriptions and specialties on LinkedIn is crucial for crop and food management companies because it helps identify industry trends and competitive positioning. By examining how companies present themselves, these businesses can gain insights into prevailing market demands, innovative practices, and emerging technologies. This knowledge allows them to refine strategies, enhance performance, and better align their services with market needs, increasing their relevance and appeal to potential clients and partners.

Methods

Understanding the main directions and performance of the industries that engage with crop and food management is very important for examining not only these core aspects, but also for making a considerable comparison among these important fields of study. By looking at these key points, we can see how companies engage in LinkedIn, helping to decide what future avenues may exist, and what amendments can be done to better manage and practice sustainable management.

Machine learning (ML) techniques, like Latent Dirichlet Allocation (LDA), can be useful tools for analyzing large amounts of information and finding hidden patterns and topics in the data. By using LDA, we can identify and organize the main focus areas in company engagement, based on their description and specialties, giving valuable insights into current priorities and guiding future studies. This method has been used many times in similar studies, especially in the areas of sustainability and circular economy (Tsironis et al., 2024).

Results

According to Table 1, the LDA topics highlight two main themes in the context of crop and food management. Specifically, for crop, topic 1 focuses on crop management, emphasizing the roles of companies, services, and products in the agricultural sector, also underscoring the importance of agricultural research, technology development, and quality management, indicating a strong interest in advancing agricultural practices through innovative solutions and business strategies. Similarly, topic 2, centers around farmers and sustainable agriculture, with an emphasis on farming management, technological solutions, data-driven practices, pointing out a trend towards industry practices aimed at enhancing food production systems. Overall, these topics reveal a comprehensive view of the agricultural landscape, where technology and sustainability play crucial roles in improving both crop management and overall agricultural productivity.

Table 1: Topic analysis for crop and food management

Crop Management		Food Management	
Topic 1	Topic 2	Topic 1	Topic 2
Crop	farmers	food	food
management	agriculture	management	management
Company	farming	safety	business
services	management	quality	service
products	crop	industry	marketing
agricultural	agricultural	training	industry
research	sustainable	company	restaurant
soil	solutions	iso	company
development	technology	service	hospitality
farm	practices	services	experience
agriculture	data	haccp	dining
farmers	quality	sales	development
quality	soil	compliance	services
business	services	development	restaurants
farming	precision	audits	institute
solutions	farm	chain	research
production	food	consulting	processing
technology	future	clients	national
provide	industry	based	providing
plant	systems	products	market

In a similar vein, regarding food management, topic 1 is primarily concerned with aspects of food safety, quality management, and industry standards, emphasizing training, compliance with regulations, auditing, and consulting services provided by companies to ensure food safety and quality throughout the supply chain. This topic underscores the importance of maintaining high standards in food management through systematic approaches and professional services. Topic 2, on the other hand, focuses on the business and service aspects of the food industry, highlighting the roles of marketing, restaurant and hospitality management, customer experience, and market development. This topic addresses the broader industry context, including company operations in the restaurant sector, service quality, and the importance of a strong market presence. Overall, these topics reveal a comprehensive view of food management, balancing the need for ensuring safety and quality measures with effective business and service strategies to enhance the overall industry performance.

Conclusion

While crop management is more centered on production and sustainability, leveraging technology and research to improve agricultural outcomes, food management combines safety and quality measures with robust business strategies to enhance the overall industry performance. Both fields underscore the importance of quality and technological advancements, but their applications and priorities differ, reflecting the unique challenges and goals within each sector. Future work could focus on the amount of adoption of advanced technologies and sustainability practices across both crop and food management to address sector-specific challenges and enhance overall performance.

Keywords

Crop; Food; Management; LDA; Topic Analysis.

Presenters profile

Konstantinos Tsagarakis is a Professor of "Economics of Environmental Science and Technology" in the School of Production Engineering and management at the Technical University of Crete. He holds a degree from the department of Civil Engineering of the Democritus University of Thrace, a BA degree from the Department of Economics of the University of Crete and a Ph.D. Degree in Public Health from the School of Civil Engineering from the University of Leeds, UK. His research interests include: circular economy, technical–economic project evaluation; environmental and energy economics; public health economics; environmental and energy behavior; big data; online behavior; environmental performance of firms; quantitative methods.

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Analysis of Relationship between Maize Production and Fertilizer Imports in Malawi: Auto Regressive Distributed Lag (ARDL) Model Approach to Cointegration

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Abstract

This paper provides an analysis of the relationship between maize production and fertilizer imports and other factors such as fertilizer prices and rainfall. The inorganic fertilizer was liberalized which allowed entry of multinational companies into the country to begin supplying inorganic fertilizer. Smallholder farmers have been cultivating maize crops for a long time, the land lacks organic matter and vital nutrients like Nitrogen, Phosphorus, and Potassium. Understanding the relationship is very important because it can help the government and other stakeholders as to whether the interventions, they are undertaking are achieving intentions including policy changes. The study used the Autoregressive Distributed Lag (ARDL) Model to analyse if there is a relationship between fertilizer imports and maize production in Malawi using time series ranging from 1992 to 2021. The two models are used to represent the relationship between the two types of inorganic fertilizer and maize production in Malawi Some farmers use both inorganic fertilizers in their maize crop whilst others use either Urea or NPK. Hence, by splitting them, it would highlight how each affects maize production. The results that there is a long relationship between maize production and urea imports as depicted by the equation. Urea imports play an important role in maize production. A one percent increase in urea imports leads to a 14.6 percent increase in maize production. However, NPK imports are not significant. The error correction term is highly significant. The speed of adjustment is high with (-1.24033). The model is adjusting at the speed of 124 percent per annum. An increase in land under maize production leads a to 144 percent increase in maize production. This is significant at 5 percent level. Rainfall is very important in maize production. An increase in rainfall increases maize production. An increase in one percent of rainfall increases maize production by 96 percent.

Keywords

Maize, Fertilizer, Production, Imports and Land

Presenter Profile

Mr. Ian Kumwenda holds a Master of Science degree in Agricultural Economics from the University of Aberdeen and a Bachelor of Science degree in Agriculture from the University of Malawi. He has more than 25 years of experience in agricultural development including more than 20 years working across SADC and COMESA on agriculture-related policies. For 25 years, he worked for the Malawi Government in the Ministries of Agriculture and the Malawi Agricultural Sector Investment Program (MASIP). He has more than 10 publications in the field of his expertise

Introduction

Fertilizer use is remarkably lower in Sub-Saharan Africa (SSA) than in other budding regions (Liverpool-Tasie et al., 2017). According to the New Partnership for Africa's Development (NEPAD), the African Union (AU)'s technical department, has some goals of pushing the agricultural productivity agenda in Africa and influencing the agricultural sector growth by at least 6% annually. SSA has already been proven to be one of the poorest regions in the world (Basu et al., 2000). Therefore, the lack of fertilizer use has reasons that are stemmed from such a predicament. These reasons are (1) lack of credit to finance their inputs costs that would help elevate crop production, (2) distance proximities where farmers travel long distances to nearest fertilizer retailers (3) inadequate market infrastructures, and (4) inefficient government assistance ((Birner & Scheiterle, 2016; Croppenstedt et al., 2003; Liverpool-Tasie et al., 2017). In 2004, it was reported that SSA usage of fertilizer was relatively 9kgs per hectare which was the lowest of all the regions. Sadly, this has not changed as it remains the region with the lowest inorganic fertilizer usage to date (Xu et al, 2009). However, the balanced use of better-suited inputs upholds technical catch-up in emerging nations and increases efficiency. With this in cognizance, African determinations were established by the Abuja Declaration on Fertilizer for the African Green Revolution (June 2006). This elaborates that AU member states have dedicated aggregate levels of fertilizer intake across the continent to 50 kg of nutrients per hectare.

Agriculture is considered one of the main engines of economic growth in Malawi. It accounts for about 35% of the gross national product whilst absorbing more than 75% of the labour force. Thus, conceivable food security and household income promotion are seen through agricultural practices. Maize is the staple food crop in Malawi, hence considered one of the essential crops produced and consumed within the country (Minot et al., 2000). Among other crops are soybean, cowpea, rice, and sorghum. Farmers utilize inorganic fertilizers mostly on maize as it is their dominant food crop (Minot et al., 2000; Waddington et al., 2020).

Since Malawi smallholder farmers have been cultivating maize crops for the longest time, the land lacks organic matter and vital nutrients like Nitrogen, Phosphorus, and Potassium. Crop rotation methods and use of manure have been used to combat this problem, but they have been realized to not be enough if maize production is to increase in the country. Due to these reasons, farmers have resorted to the use of inorganic fertilizers to aid in maize production. When the inorganic fertilizer is paired well with satisfactory rainfall and cropping conditions, farmers are likely to attain good responses to fertilizer imports that are used as inputs in the farming process (Waddington et al., 2020).

Malawi began using inorganic fertilizers many decades ago. However, starting in 1995, structural reforms were launched in which they were aimed at increasing agricultural productivity, especially among smallholder farmers (Minot et al 2000). Private fairness may perhaps improve domestic financing, agreed with the high bank interest rates and weaknesses in financial intermediation in most of Africa (ERA, 2015). Private equity savings has escalated severely in Africa over the past epoch notwithstanding a very low base with average yearly growth of 26%, which imitates an enhanced commercial atmosphere (ERA, 2015).

The inorganic fertilizer was liberalized which allowed the entry of multinational companies into the country to begin supplying inorganic fertilizer, for instance, Norsk-Hydro. Other domestic firms also joined in the supplying of fertilizer, that as the Agricultural Development and Marketing Corporation (ADMARC) and Smallholder Farmer Fertilizer Revolving Fund of

Malawi (SFFRFM). One should keep in mind that Malawi imports inorganic fertilizer that is distributed to farmers. This automatically means that fertilizer prices are greatly exposed to devaluation, affecting the prices of maize in the country. Nevertheless, Malawi remains one of the first countries in SSA to commit to structural and policy reforms concerning agricultural productivity (Govindan & Babu,1996; Minot et al, 2000).

Literature Review

Some studies have been done in Malawi concerning the issue of fertilizer and crop production. However, these studies have not touched on the relationship between fertilizer imports and maize production. For example, Babu and Govindan (1996) worked on a case study in Malawi in which they investigated supply response under fertilizer market liberalization. Most of the farming activities are especially done in the rural areas which do not have or low functional Agro-dealers (one-stop shops where farmers be able to get the farming equipment's) as they are likely to focus in towns and in additional big to municipals that are far away from the farmers, henceforth creating fertilizers unreachable to farmers (Jayne et al., 2013; Sheahan, et al., 2013). Furthermost, farmers are over 20 km away from the neighbouring input shop (Roy, 2016).

Their main agenda was to explore if the policies and programs implemented in Malawi are working or not. They found out that the policies were ineffective as policymakers had a poor understanding of how farmers would react if prices changed in the market. They recommended better policymakers who understand the deep relationship between input-output relationship, thus helping in boosting agricultural production in the country. Another study was done by Berry et al (2000) on fertilizer liberalization in Malawi and Benin. They employed the Heckman model to investigate the determinant of fertilizer use for data ranging from 1980 to 1997. It was found out that little to no subsidy on fertilizer increased fertilizer use in Malawi by only 30% during this period, proving slow agricultural growth in the country. Additionally, the few farmers who bought fertilizer in Malawi were doing it through micro-credit which they even deemed expensive.

The studies above show that there is still a literature gap that needs to be covered in Malawi where one needs to know the relationship between fertilizer use and maize production. Hence, the paper will dive deep into analysing such a relationship in Malawi and come up with a conclusive answer. By knowing if this relationship exists, one can be able to answer if the policy reforms are working presently or not as fertilizer imports having a positive effect on maize production would indirectly translate to the Affordable Input Program (AIP) also working in the country.

Even though no literature exists on this topic in Malawi, other African countries have tried to explore this relationship. Beginning with Zambia, Black et al (2006) explored the relationship between fertilizer use and maize yield response and its profitability among local farmers in Zambia. Regression results suggested that maize yield production was high for farmers who planted on time as this was in sync with the rainfall and fertilizer application. Profits were only made in areas where input-output price ratios were favourable. They found distance and transportation expenses to the supplying centre's to be a factor leading to farmers not profiting from fertilizer usage as these expenses alone are huge. Also, they recommend the distribution of inorganic fertilizer on time as most subsidized fertilizer in Zambia gets distributed late, thus disrupting the farming calendar which leads to low yield regardless of fertilizer use.

Another study on the same topic is from Birner and Scheiterle (2016) who investigated factors affecting maize production in the Northern part of Ghana using the Policy Analysis Matrix and Cobb Douglas function. They found that inorganic fertilizer was at the centre of maize production where proper usage of inorganic fertilizer mixed with technological and environmental advancements would lead to effective maize production in the country. They recommended Malawi for having an effective fertilizer subsidy program from 2005 to 2007 and hope that their country will follow suit in the effective and efficient distribution of subsidized inputs in the country.

The fertilizer supply chain in Malawi is not as efficient as it could be, in part because Malawi is a landlocked country – resulting in high agricultural input costs. Lack of efficient logistics systems (roads and rail) from the nearest port in Mozambique (Nacala) and high costs of local currency due to an unstable foreign exchange constrains accessibility to fertilizer by small market actors, specifically rural Agro-dealers and smallholder farmers. Fertilizer imports are largely dominated by the subsidy programme (AFAP,2021)

The main fertilizers supplied in Malawi are as follows; NPK, UREA, CAN, Super D Compound, 23:21:0+4S, NPK 25:05:05 and similar high-N (Tea), 6:20:24 + 3S + 0.5Zn (soybean, Groundnuts), 10:20:20 + 6S (sweet Potato). Malawi has two companies that blend and granulate fertilizers. Malawi Fertilizer Company (MFC) blends fertilizers while Optichem Malawi both blends and granulates fertilizers. Optichem Malawi blends 20,000 Mt of fertilizer and granulate 15,000 Mt of fertilizer annually.

The paper is going to follow this order: section 2 provides the data collection and methodology of the paper. This will be followed by results and discussion in section 3. Section 4 is recommendations. Then it closes with a conclusion in section 5.

Data and Methodology

Data

The study used annual data from the year 1990to 2020 sourced from FAOSTAT and World Bank Development Indicators, and National Statistical Office Malawi. The selected variables in the model capture different dynamics driving maize production in Malawi. The fertilizer variables indicate prices that drive maize production in the domestic market (Table 1). Domestic production of maize aids in the understanding supply-side effects of in a country.

The maize prices facilitate the analysis of cross-commodity price relationships and substitution effects, especially given that maize is one of the staples grown in Malawi, mean rainfall greatly affects agricultural output and variability in production levels.

Maize Production

Maize is a crucial crop in Malawi, serving as the staple food for the majority of the population. However, recent reports indicate a decline in maize production. For the 2022/2023 season, maize production decreased to approximately 3.51 million metric tons, a 5.6% drop from the previous year's estimate1. This decline is attributed to factors such as reduced input uptake, unfavourable weather conditions, and a decrease in both planted area and yield.

Maize production in the previous year

In the 2021/2022 season, Malawi produced approximately 3.72 million metric tons of maize[1]. This was a slight increase compared to the 2022/2023 season, where production dropped to about 3.51 million metric tons.

The higher production in the 2021/2022 season was due to more favorable weather conditions and better input uptake[2]. However, challenges such as reduced input use and adverse weather conditions have impacted the subsequent season's yield.

Production in previous year can have an effect on the following year outcome depending on level of production. In the case of high production, it is expected that this would depress price and prompt farmers to increase production to take advantage of the price increase.

Table 1: Variable description

Variable	Description	Measurement
MY_t	Maize production indicates the average local maize production per annum	Metric tonnes
MYt−1MYt−1	Maize production in the previous year.	Metric tonne
Ureat−jUreat−j	Price of Urea for top dressing.	USD per Metric tonne
Raint−m +Raint−m +	Rainfall per annum.	Millimetres per year
MPt−cMPt−c	Maize price, market conditions and their possible influence on domestic maize production	USD/ metric tonne
FPt−dFPt−d	Fertilizer Price for basal dressing.	USD/metric tonne

Rainfall

Malawi experiences a tropical climate with distinct wet and dry seasons. The wet season typically runs from November to April, during which the country receives the majority of its annual rainfall. The dry season spans from May to October.

Annual rainfall varies significantly across the country:

- Northern regions: Generally, receive more rainfall, with some areas getting over 2,000 mm (79 inches) per year.
- Central regions: Including Lilongwe, receive around 900 mm (35 inches) annually.
- Southern regions: Areas like Blantyre receive about 1,127 mm (44 inches) per year.

Maize Price

Maize prices are determined by government minimum prices that based on gross margin analysis undertaken by the Ministry of Agriculture every season. Prices tend to vary depending on the supply and demand.

[1] https://knoema.com/data/agriculture-indicators-production+malawi+maize

[2] https://fews.net/southern-africa/malawi/food-security-outlook/october-2021

Fertilizer Prices

Most of the components that determine the price of fertilizer sold in Malawi is determined abroad. SFFRFM and ADMARC face the same FOB, CFR, port fees and cost of transport to Malawi, as the private sector. The studies show that the externally determined costs make up 85 percent of the retail price. Malawi Bureau of Standards (MBS) and other fees and the cost of financing, which together make up another 5 percent, will also be similar for private suppliers and parastatals without additional Government intervention. The parastatals are also likely to face similar costs of redistribution in Malawi (2.5 percent of retail price) insofar as they have to hire private haulers to transport fertilizer to retail locations. The parastatals would therefore have to find savings in the remaining 7.5 percent of overall costs in order to offer a lower price than the private sector (IFFPRI,2021).

Fertilizer imports

The Institutional arrangement in the fertilizer industry is based on the functions to be carried out. Historically, the government has played a role on the supply side through imports (using tender-bids) and distribution by state agencies, and on the demand side through a voucher program distributed to selected farmers to incentivize effective demand. The main role of the private sector is importing and supplying to the government for distribution to the public through the subsidy program. However, the private sector also plays a major role in the trade through sale of fertilizer on the open market to estates and for the production of cash and commercial crops.

Land under Maize Cultivation

Of the 4.7 million hectares of land which can be cultivated under rain fed and irrigated agriculture, only 2.5 million hectares are under cultivation. Fifty per cent of all cultivated area is dedicated to cereals with maize accounting for 46%. The average landholding per household is 1.2ha. The average land per capita is 0.33ha. (Government of Malawi and World Bank 2006). The poor hold 0.23ha per capita and the non-poor hold 0.42ha per capita (AFAP Baseline, 2017). There are differences on the land sizes for farming between 3 groups of producers in Malawi. (AFAP,2021)

Methodology

The study used Autoregressive Distributed Lag (ARDL) Model to analyze if there is a relationship between fertilizer imports and maize production in Malawi using time series ranging from 1992 to 2021. This methodology possesses features that suit the time series data for this paper. For instance, the data is of a small sample size which works well with the ARDL model. Moreover, the variables involved in this paper do not need to be of the same order as the model takes on variables with integration of order 1 and/or 0, thus the variables need not be stationary (Pesaran et al., 2001).

This model has been selected for the study as it suits the data better due to its small sample size of 29 years. The model also takes on variables of zero and/or one order of integration. Since the maize and fertilizer variables are prone to overflowing in the next year, the model is a dynamic model that incorporates exogenous and endogenous variables. The study also tests whether there are relationships in the short run and/or long run, thus helping policymakers in making concrete and effective decisions that can help farmers in the country. With all the features that it possesses, the model will accordingly help in producing unbiased and valid results.

The relationship between the dependent and independent variables has an econometric model presented below.

MY_t = ∂0j+ ∑pj=1β1j MYt−1+ ∑j=0qβ2j Ureat−j + ∑m=0rβ3m Raint−m +∑c=0fβ4c MPt−c+∑d =0sβ5d FPt−d+Ejt∂0j+ ∑j=1p𝛽1j MYt−1+ ∑j=0q𝛽2j Ureat−j + ∑m=0r𝛽3m Raint−m +∑c=0f𝛽4c MPt−c+∑d=0s𝛽5d FPt−d+𝓔jt (1)

MY_t = ∂0j+ ∑pj=1β1j MYt−1+ ∑j=0qβ2j NPKt−j + ∑m=0rβ3m Raint−m +∑c=0fβ4c MPt−c+∑d= 0sβ5d FPt−d+Ejt∂0j+ ∑j=1p𝛽1j MYt−1+ ∑j=0q𝛽2j NPKt−j + ∑m=0r𝛽3m Raint−m +∑c=0f𝛽4c M Pt−c+∑d=0s𝛽5d FPt−d+𝓔jt (2)

The two models above represent the relationship between the two types of inorganic fertilizer and maize production in Malawi. As one can see, the models have been split into two equations as the paper wants to analyse the relationship of each inorganic fertilizer to maize production. Some farmers use both inorganic fertilizers in their maize crop whilst others use either Urea or NPK. Hence, by splitting them, it would highlight how each effect maize production.

MY_t is a vector, and it denotes the current dependent variable in the model which is maize production. The *∂0j* is the intercept in the model which is normally called the drift. The independent variables, Urea and NKP, have been denoted with their vowel representations that incorporate lagged values. The same is seen in the controlled variables where the rest of the variables are represented by their vowels. The p and q represent the lag optimal for the dependent and independent variables. *Ejt* is the vector of error terms in the model that follows the white noise distribution. Therefore, the model is a dynamic model that shows the current dependent variable and its lagged values, at the same time displaying the current explanatory variables and their lagged values. The lagged values need not be the same length as the model allows for different lag lengths.

Before the model is applied, some steps need to be followed to test if the model's prediction is valid or not. The paper begins with unit root testing to test for stationarity. This is followed by lag optimal selection to determine the lag length of each variable (Gujarati, 2003). Then the bounds test testing follows and determines if there exists a long-run relationship or not. If the long-run relationship exists, the analysis continues to apply the ARDL model that uses the error correction model (ECM) to explain the relationship that exists both in the short run and the long run ((Davidson & MacKinnon, 2004; Nkoro & Uko, 2016). The model incorporating the ECM is denoted below.

MY_t = ∂0j+ ∑pj=1β1j ΔMYt−1+ ∑j=0qβ2j ΔUreat−j + ∑m=0rβ3m ΔRaint−m +∑c=0fβ4c ΔMPt−c+∑d=0sβ5d ΔFPt−d+∃ECTt−1+Ejt∂0j+ ∑j=1p𝛽1j ΔMYt−1+ ∑j=0q𝛽2j ΔUreat−j + ∑m=0r𝛽3m ΔRaint−m +∑c=0f𝛽4c ΔMPt−c+∑d=0s𝛽5d ΔFPt−d+∄ECTt−1+𝓔jt (3)

MY_t = ∂0j+ ∑pj=1β1j ΔMYt−1+ ∑j=0qβ2j ΔNPKt−j + ∑m=0rβ3m ΔRaint−m +∑c=0fβ4c ΔMPt−c +∑d=0sβ5d ΔFPt−d+∃ECTt−1+Ejt∂0j+ ∑j=1p𝛽1j ΔMYt−1+ ∑j=0q𝛽2j ΔNPKt−j + ∑m=0r𝛽3m ΔRaint−m +∑c=0f𝛽4c ΔMPt−c+∑d=0s𝛽5d ΔFPt−d+∄ECTt−1+𝓔jt (4)

The Δ stands for the first difference. The ∃ and ∄ is the ECM coefficient for short-run dynamics in the model. The ECM exhibits the speed of adjustment in the long run from the short-run shocks. After finding the relationship between the variables, the Granger causality test is undertaken to see if there exists a causation between fertilizer imports and maize production.

Seasonality is embedded in ARDL model, and it has been explained in the model. It is expected that there will be a positive relationship between rainfall and maize production. Higher rainfall leads to higher maize production and vice versa. This variable is important because it has implications for climate change in Malawi.

Empirical Results and Discussion

Trends and descriptive analysis of the key variables

The graphs depict how the variables are displaying their characteristic over time. The figure below shows that for maize, production is increasing over time.

The mean 2.3 million tonnes with maximum of 4.5 and minimum of 612 metric tonnes. The median is 299 million metric tonnes which is the most frequent achieved by the smallholder farmers.

Fertilizer prices

As of recent reports, the prices for urea and NPK (Nitrogen, Phosphorus, and Potassium) fertilizers in Malawi have seen a significant increase. Specifically, a 50 kg bag of urea is priced around MWK 84,700, while a 50 kg bag of NPK is priced at approximately MWK 85,000. These prices represent a substantial rise from previous levels, where they were about MWK 70,000 and MWK 71,500, respectively

This surge in fertilizer costs has been attributed to several factors, including global market dynamics and the devaluation of the Malawian Kwacha. This has raised concerns among farmers and agricultural experts about the potential negative impacts on crop production and food security in the country.

Fertilizer imports

Malawi imports significant quantities of urea and NPK fertilizers to support its agricultural sector. For example, in 2023-2024, the government contracted 13 companies to supply 149,164 metric tons of NPK and urea fertilizers under the Affordable Inputs Programme (AIP). These companies include Optichem (2000) Limited, ETG Inputs Ltd, Farmers World, and others. This initiative aims to provide subsidized fertilizers to smallholder farmers, with about 80,000 metric tons already in the country. However, despite these efforts fertilizer uptake by farmers is still low.

The high prices of fertilizers in Malawi have been a challenge, influenced by various factors such as global market dynamics and logistical costs. The government has been working to address these issues by ensuring timely procurement and distribution through programs like the AIP. In terms of specific import quantities, Malawi imported 446,649 tons of urea in 2020. This quantity has shown fluctuations but generally increased over recent years, reflecting the growing demand for fertilizers in the country as a result of new programs such as Mega farms, irrigation and others

Rainfall

Malawi's rainfall is highly seasonal, with the majority falling during the wet season from November to April. The country experiences significant variations in annual rainfall, influenced by geographical factors such as altitude and proximity to Lake Malawi. The central and northern regions typically receive more rainfall than the southern regions. The country's agriculture, which is a critical part of its economy, heavily depends on this seasonal rainfall. However, Malawi is also prone to extreme weather events such as droughts and floods, which can severely impact agricultural productivity and livelihoods.

Maize prices

The price of maize in Malawi varies across different markets. In major cities like Lilongwe and Blantyre, the retail price of maize is around MWK 989.07 per kilogram (approximately USD 0.96). The government set a minimum farm gate price for maize at MWK 650 per kilogram to support farmers.

Maize prices have been volatile due to factors such as adverse weather conditions and lower harvests, which have affected supply and driven prices higher. Additionally, price increases have been noted compared to the previous year, highlighting ongoing challenges in the agricultural sector and food security concerns.

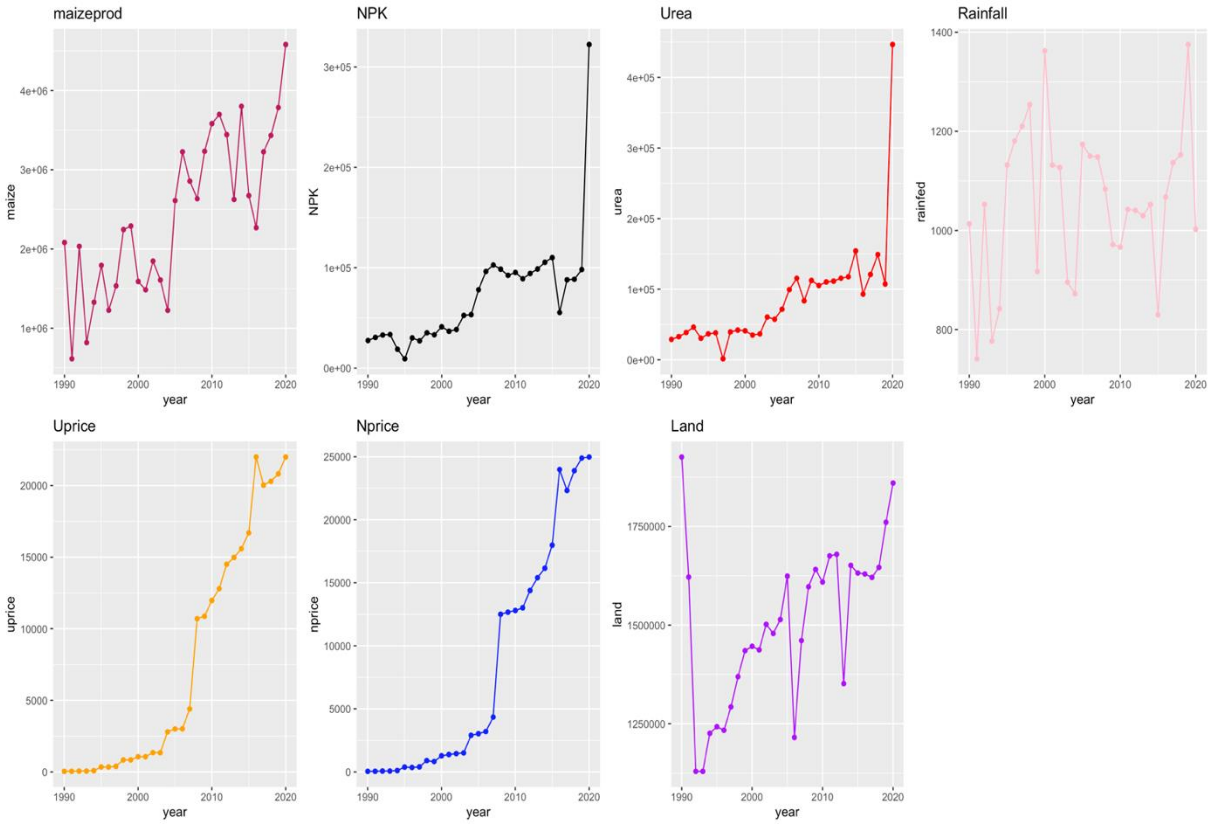

Figure 1: Trends in the different variables present in the paper (data ranging from 1990 to 2019).

Table 2 shows the variables that are used in the model. These variables should satisfy certain criteria (variance and mean should remain constant throughout the model and Gaussian distribution should be existing for all the variables). Fertilizer imports are measured in metric tons, rainfall in millimetres, land in hectares, prices in Malawi Kwacha, and maize production in metric tons.

Table 2: Descriptive statistics for the variables present.

Statistics	Maize production	Urea imports	NPK imports	Rainfall	Land	Urea price	NPK price
Minimum	613940.00	1438.00	9280.00	740.90	1129327.00	40.70	45.01
Median	2290018.00	71556.00	55384.00	1052.50	1513929.00	3002.00	3027.50
Mean	2432509.00	86441.00	71399.00	1055.90	1504405.00	7558.70	8297.70
Maximum	4581524.00	446650.00	322418.00	1375.30	1925802.00	21992.00	24970.01
Observations	31	31	31	31	31	31	31

Optimal lag selection and stationary test

The results in Table 3 provides the results of Augmented Dickey Fullar Tests and indicates that the variables have different orders of integration confirming that the right model is the ARDL since it can handle variables that have different orders of integration. The data from 1990 to 2019.

Table 3: Augmented Dickey-Fuller test.

Variables	(ADF test statistic) in levels	(ADF test statistic) for 1st difference	Integration order	Lag-Lengths
Maize production	-2.52	-3.68**	I(1)	2
Urea imports	-2.82	-3.68**	I(1)	3
NPK imports	-3.01	-3.98**	I(1)	3
Rainfall	-3.67*	-5.02***	I(0)	1
Land	-2.93	-4.08*	I(1)	3
Urea price	-1.18	-3.69**	I(1)	2
NPK price	-1.29	-3.60**	I(1)	0

The ***, **, and * represents 0.01, 0.05, and 0.1 significance level. If the value is not within these ranges, then do not reject the null hypothesis.

ARDL bound test for cointegration

After establishing the existence of the long-run relationship between fertilizer consumption and maize production, the ARDL model to cointegration results are displayed (Table 4). These are both short and long-run results. They are accompanied by the Granger causality check of this relationship.

Table 4: displaying the cointegration/bounds test results of the main variables investigated.

Fertilizer intake proxy	Level of significance	Bounds critical values		F statistic
Urea Imports		Lower	Upper	
	1%	4.324	5.642	
	5%	3.116	4.094	4.179
	10%	2.596	3.474	
NPK Imports		Lower	Upper	
	1%	4.324	5.642	
	5%	3.116	4.094	4.289
	10%	2.596	3.474	

Results from Bound Test

The results are for Urea and NPK using bound testing (Table 5). The F test for Urea show that the F value is less than the critical value at 1 percent but higher at 5 and 10 percent significant levels. Indicating that there is a long relationship between maize production and urea imports.

The F test for NPK show that the F value is less than the critical value at 1 percent but higher at 5 and 10 percent significant levels. Indicating that there is a long relationship between maize production and NKP imports.

Table 5: Long-run results of the variables present in the time series paper (dependent variable is maize production).

Variables	Coefficients	Standard errors	P values
Lagged maize production	-1.4430	0.3080	0.000665 ***
NPK imports	1.0554	0.3647	0.0146 *
Urea imports	0.7105	0.0491	0.2335
Land	-1.3648	1.6086	0.4143
Urea price	-1.6525	0.7637	0.0533
NPK price	-1.6993	0.8296	0.0652
Rainfall	1.7539	0.7326	0.0356*
Constant	17.4325	25.6382	0.5106

*** represents 1% significance level, ** represents 5% significance level and * represents 10% significance level.

The results indicate coefficients in the short run. The lag maize shows a significant relationship with the current maize. An increase in maize production in the previous year leads to a reduction of maize in the current year by 1.44 percent. This is highly significant at 1 percent.

The other important variables include NPK imports, urea imports, urea price, NPK price, and land. NPK imports increase maize production while urea imports do not significantly increase maize production

An increase in the nominal price of fertilizers leads to a decrease in maize production by 1.6525, and 1.6993 for urea and NPK respectively. Imports also lead to a decrease in land under maize.

Rainfall has a positive relationship with maize production as expected. It is significant at 10 percent. Land has a negative relationship with maize production. A one percent increase in fertilizer imports is associated with a decrease in land under maize.

The ECM Results

Urea imports play an important role in maize production. A one percent increase in urea imports leads to a 14.6 percent increase in maize production (Table 6). However, NPK imports are not significant. The error correction term is highly significant. The speed of adjustment is high with (-1.24033). The model is adjusting at the speed of 124 percent. An increase in land under maize production leads to a 144 percent increase in maize production. This is significant at a 5 percent level. Rainfall is very important in maize production. An increase in rainfall increases maize production. An increase of 1 percent in rainfall increases maize production by 96 percent. These results agree with the expectations.

Table 6: ECM results that also include the short-run results (explained variable is △Maize production).

Variable	Coefficients	Standard errors	P values
△ NPK imports	0.06753	0.12309	0.590019
△ Urea imports	0.014635	0.003414	0.000237
△ Land	1.43669	0.45323	005302 **
△ Rainfall	0.96282	0.29308	0.004114 **
△ NPK price	-0.23451	0.16591	0.174573
ECM(-1)	-1.24033	0.26217	0.000167 ***
Constant	24.09195	5.08040	0.000163 ***
R squared	0.7229		
S.E of regression	0.2141		
F test	5.218		0.001436***

*** represents 1% significance level, ** represents 5% significance level and * represents 10% significance level.

Diagnostic checks

The diagnostics tests were done for serial correlation and the P value is greater than 1 (Table 7), indicating that there is no serial correlation and there we cannot reject the hypothesis. The null hypothesis is that there is no heterokedastity therefore we cannot reject the null hypothesis. For normality test the null is that there is normally and therefore we cannot reject the null hypothesis.

Table 7: More diagnostic checks.

Diagnostic test	T statistic	P value
Serial correlation	0.34509	0.5569
Heteroskedasticity	17.34	0.4316
Normality	0.54198	0.4785

Granger causality

The Granger causality tests are performed to check the direction of causality of the key variables in the models (Table 8). The hypothesis that NKP does not granger cause, maize is rejected, therefore the results indicate that NPK granger cause maize production. The hypothesis that maize production does not granger cause NPK is rejected at a 10 percent significant level. Therefore, maize granger cause NPK imports. The hypothesis that urea does not granger because Maize production is rejected at a 5 percent significance level. Therefore, urea granger causes maize production. The hypothesis is that maize production does not granger cause urea imports. This cannot be rejected.

Stability check

By confirming that the long-run associations exist between variables, the study applies the cumulative sum (CUSUM) and cumulative sum of square (CUSUMSQ) tests. Previous studies have suggested these tests portray the good fitness of the ARDL model. These tests are used to plot the residual of ECM (Figure 2). If the statistics in the plot fall in critical bounds at a 5% significant value, the results suggest that the coefficients of the ARDL model are stable.

Table 8: Granger causality test results.

Null hypothesis	Observations	P values
NKP does not granger cause Maize production	31	0.001129 **
Maize production does not granger cause NPK	31	0.03033 *
Urea does not granger cause Maize production	31	0.003709 **
Maize production does not granger cause Urea	31	0.2216

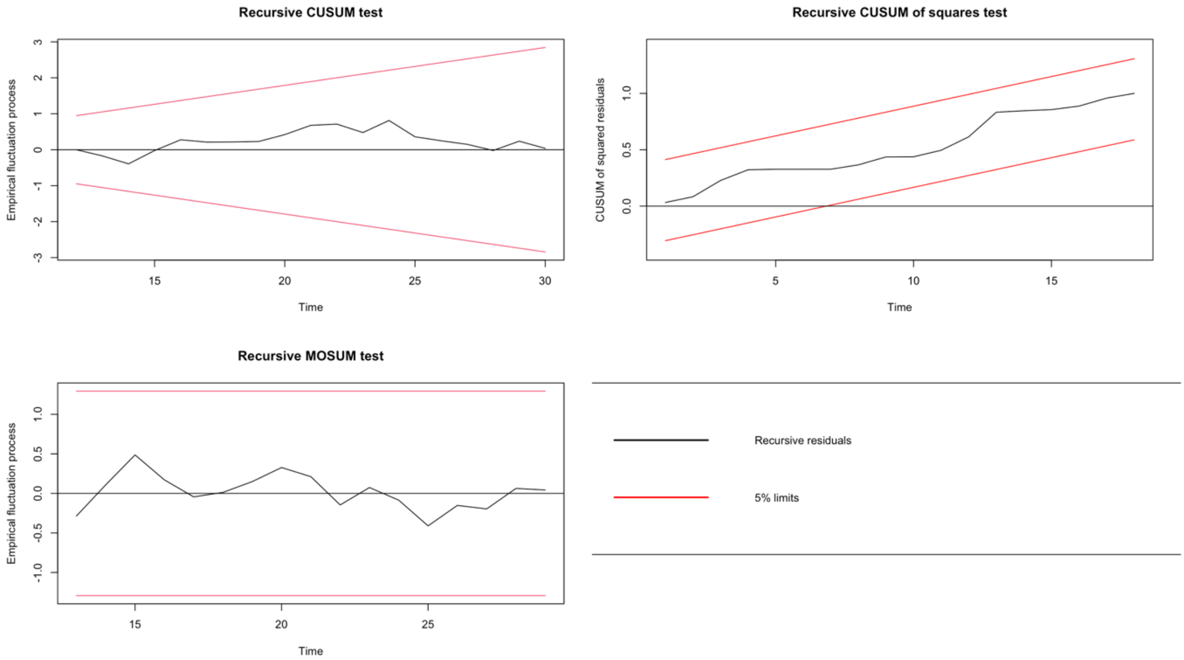

Figure 2: CUSUM and MOSUM graphs after the stability test.

Study Limitations

What are the data limitations There are imitations of the study that render scope for further research segment/section. The current study has not considered the exchange rate as a variable that affects fertilizer prices and maize prices. It is important to consider this variable because devaluation of Malawi Kwacha affects fertilizer and maize prices negatively. Liberalization of the markets is another key policy variable that can affect maize prices, fertilizer prices and amount of imports of fertilizers. It can be modelled as a dummy variable.

Conclusion and Recommendations

The paper has analysed the relationship between fertilizer imports as a proxy for fertilizer consumption in Malawi to find out whether there is a relationship between the two. The paper has also highlighted some of the exogenous variables that affect maize production such as rainfall, land under maze cultivation, and prices of the fertilizer. Overall, there is a positive relationship between the two variables.

Generally, evolvement on the way to the Abuja target can create positive gains though slow, this study has explored the nitty-gritty of both domestic and international strategies as far as accelerating intensification and productivity improvements. Hitherto what policies can increase fertilizer usage, hence with the diagnostic studies of the fertilizer sector and analyses of the reasons behind low levels of fertilizer adoption and/or consumption by farmers.

An increase in the nominal price of fertilizers leads to a decrease in maize production by 1.6525, and 1.6993 for UREA and NPK respectively. It is significant at 10 percent. The results are for Urea and NPK using bound testing. The F test for Urea show that the F value is less than the critical value at 1 percent but higher at 5 and 10 percent significant levels. Indicating that there is a long relationship between maize production and urea imports. Likewise, the UREA and NPK have been first preferred by many farmers' maize production and incorporated with fairly prevailing prices.

Though, the 2022/ 2023 growing season, the results indicate coefficients in the short run. The lag maize shows a significant relationship with the current maize. An increase in maize production in the previous year leads to a reduction of maize in the current year by 1.44 percent. This is highly significant at 1 percent; this is due to the obvious reason of low global trends in the importation and lack of continental production.

Fertilizer prices in domestic markets vary, depending on prices on the global market, political context, market structure, and transaction costs. Some authors also argue that exchange rates have an impact on domestic prices, particularly in a context where most countries import resources (Olusegun, 2012). An increase in the nominal price of fertilizers leads to a decrease in maize production by 1.6525, and 1.6993 for urea and NPK respectively. Imports also have led to a decrease in land under maize as a result of skyrocketing of these inputs at the global market due to the Ukrainian-Russia War. This resulted that most of the farmers having to diversify to other crops such as Soya beans that can do better without fertilizers.

The study also discovered that one of the productive factors of land is dwindling which has registered a negative relationship with maize production. This denotes that a 1 percent increase in fertilizer imports is associated with a decrease in land under maize. The results show that the variables are all stationary in either order I(0) or I(1). Rainfall is highly significant while maize production, area imports, NPK imports urea price, and NPK price are significant at 5 percent. The land is significant at 10 percent. This is mainly indicating that the uptake of fertilizer is still low per acre, whereby the climatological effects have a critical impact too. For growth to be enormous some factors such as land, labour, machinery (archaic tools), and farm inputs must have to be intertwined for sustainable food production.

Policy Recommendations

The right usage of fertilizer is regarded as the technology adoption in sustainable farming, as farmers expect to benefit in one of the other (a) raising the physical productivity of inputs (through adaptation is one way of improving the macroeconomic fundamentals. By adopting the technologies, farmers have been learning how to manage them, and when and when not to use them); (b) reducing the costs of input purchases by increasing efficiencies (for example, in fertilizer or seed production and/or delivery systems); and (c) increasing output prices (with either high consumer prices or with subsidies funded by taxpayers).

Rainfall

For rainfall there is need to promote irrigation development, climate smart agriculture and crop diversification.

Fertilizer imports

Reducing the costs of input purchases by increasing efficiencies (for example, in fertilizer or seed production and/or delivery systems). Promote private sector to import fertilizers but also Malawi should invest in local fertilizer production to avoid dependency on imported fertilizers and save forex.

Fertilizer Prices

Fertilizer prices in domestic markets vary, depending on prices on the global market, political context, market structure, and transaction costs. Some authors also argue that exchange rates have an impact on domestic prices, particularly in a context where most countries import resources.

Maize production

Maize yields are low at the same time area under maize is declining due to competition with other crops as a result of high price of fertilizers. Therefore, the strategy should focus on soil fertility initiative, high yielding maize varieties and crop diversification through maize production intensity which can release land for other crops.

Land under maize cultivation

Imports have led to a decrease in land under maize as a result of skyrocketing of these inputs at the global market due to the Ukrainian-Russia War. This resulted that most of the farmers having to diversify to other crops such as Soya beans that can do better without fertilizers.

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Sustainable Practices and Rural Land Values: Valuation Consideration

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Extended Abstract

With the imperative focus on sustainability in all aspects, agriculture practices and the uses of rural land have thrived to become more sustainable, limit their impact on the environment, and significantly contribute towards a greener and better planet for all. The sustainability agenda within the built environment differs extensively from that applied to agricultural land and the rural sector while still having the common goal of reducing human activities' negative impact on the planet. In meeting the sustainable agenda set by the government across all sectors, the process that incentivised the private sector must be financially viable, even more so for land managers (Warren-Myers, 2022).

The growing dissatisfaction within the farming communities around the sustainable agenda can be traced to the lack of a clear link between agri-environmental practices/schemes and their impact on the economics of agricultural activities and, crucially, land valuers. The changing goal post on the timeline to meet sustainable agenda, therefore, creates a circle of blame and inaction in many cases, which could imply that activities to improve understanding, benchmarking data, and knowledge keep being pushed further down the line as various stakeholders may lack the imperative to act of targets already set. While the UK has a 25-year environmental plan with different timelines within the goals, recent new articles show comments from the Office for Environmental Protection stating that the UK is mainly off track and notes how backtracking has occurred in the attempt to deal with climate change. (FT, 2024; DEFRA, 2023). Crucially, to appreciate the future role of valuer comes from the third recommendation of the Environment and Society Centre report on the emerging global land use crisis, which highlights the need to look at the value of land and financing of stewardship differently. A formal and institutional approach linked to regulations or payment schemes and instruments that are understood by the investment world and landowners to attain global benefits through the application of economic value to land linked to the value of biodiversity, ecosystem function, and carbon sequestration potential. The role of the rural valuer is crucial in meeting the third recommendation (King et al., 2023).

The phasing out of the Common Agricultural Policy provided by the European Union and its replacement by the Agricultural Act with devolved nations of England, Scotland, Wales and Northern Ireland developing their strategies to meet the meet UK's environmental objectives and commitments connected to agriculture (Hurley et al., 2022). The journey towards a holistic agenda to meet and achieve sustainable objectives in agricultural practices becomes even more divided. With CAP historically criticised for some fundamental weakness impacting land prices, the process changed to the three Environmental Land Management Schemes, which are expected to take effect over the coming year and place emphasis on improving the environment and the general public good, moving away from the past CAP regime of payment based on land area rather than how they are managed.

Moving from the CAP, the Department for Environment, Food and Rural Affairs (DEFRA), through co-design, attempts to facilitate a process whereby stakeholders have a say in policy development to try to ensure that ELM works for everyone; the reality of this approach is that it is set with problems and has not proven effective in providing solutions lacking in inclusivity and engagement of the farming community in the process (Tsouvalis-Gerber and Little, 2020; DEFRA, 2018). The later work of Hurley et al. (2022) shows the overarching business factors that drive agricultural production. These business factors are used to categorise non-participating ELM stakeholders into Basic Payment Scheme non-claimants (unsupported by CAP in the past), hobby farmers (privacy and autonomy over additional income from ELMS), tenant farmers (considering that ELM favours the landlord), or those lacking precise succession planning and not being able to make long term decisions (limited clarity on future planning and investment so not able to undertake ELM), low-income farmers (undertaking farming below sustainable income levels) and production farmers (commercial undertaking over public good) all who think ELM are not relevant to them furthering the distortion in establishing sustainable agricultural land practices and land value by valuers.

The behaviours of key stakeholders, such as the businesses and the government, are seen as a barrier and not an enabler to extracting market value on land, even when it is intended for public betterment (Lord and O'Brien, 2017; Payne, 2013; Adams and Watkins, 2014). With the future success of ELMs dependent on the uptake and participation by farmers as suppliers of ecosystem services, (Holt and Morris, 2022) showed that a simple cost and income foregone approach might not be sufficient but should be linked to a better understanding of the real cost of environmental actions, linked to demand-driven benefit pricing for public goods, context-specific valuation and benefit-based reward systems. From the above, valuers determine the context-specific valuation, which should differ from the traditional approach upon which agricultural land fit for ELMs is currently valued. Crucial, the view is that just like the CAP, ELMs have the potential to affect land values, rent and tenure arrangement as the intended long-term options may not suit the existing agricultural tenancy agreements but be more favourable for landowners to carry out restorative works linked sustainability and the untended consequences being the termination of tenancy agreements (Holt and Morris, 2022).

The drive for further research on having valuers consider the role of sustainability in valuation reporting shows that while the valuation body RICS has published professional standards covering sustainability and ESG in commercial property valuation and strategic advice reissued in May 2023, which covers the built and natural environment, it is hardly suitable for agricultural land use which is crucial for the rural sector and ELMs (RICS, 2022). The challenge for both the professional and clients is that while there is a willingness by professionals to engage with sustainability, certain features that are important to the client may not have considerable market value and limited evidence to show this due to limited comparables (Michl et al., 2016). Further research will investigate the knowledge level of valuers and landowners on how ELMs impact market value and document the current level of reporting valuers provide on aspects of sustainability that may impact market value.

Keywords

Environmental Land Management, Ecosystem Services, Market Value, Valuer, Valuation, Sustainability.

Presenter Profile

Dr. Itua is a Senior Lecturer in the Department of Food, Land, and Agribusiness Management at Harper Adams University. With over seven years of teaching and research experience in valuation, corporate governance, and real estate investment trusts, he received his PhD from the School of the Built Environment and Architecture at London South Bank University. His research focuses on how corporate governance influences the performance of listed real estate trusts in the United Kingdom, South Africa, and Nigeria.

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Sustainable intensification of Rice cultivation in India

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Extended Abstract

This study investigates recent initiatives in India's rice cultivation, focusing on their impact on sustainable intensification, water use, and greenhouse gas (GHG) emissions. Rice cultivation has been a cornerstone of India's agricultural sector since independence, significantly contributing to the GDP. However, traditional methods have posed sustainability challenges due to high water usage and GHG emissions. India, being one of the largest rice producers and exporters globally, faces the critical need to adopt more sustainable practices. The study aims to assess the effectiveness of new agricultural practices in enhancing rice production, reducing water requirements, and controlling GHG emissions. By evaluating recent innovations and their impact on productivity, this research seeks to compare the gains achieved through these methods with traditional practices. The focus will also be on understanding changes in water usage and determining if these initiatives have successfully reduced the water footprint of rice production. Additionally, the study will measure the impact of new cultivation techniques on GHG emissions, identifying specific practices that contribute to emission reductions. By addressing these key areas, the study aims to contribute to making Indian rice cultivation more sustainable and environmentally friendly while maintaining or enhancing productivity. This research is crucial for developing strategies that balance agricultural productivity with environmental sustainability.

Rice has played a significant role as a staple cereal globally, with notable periods of relevance from 1960-1980 and 1991-2010. However, the decades spanning 1980-1990 and the period from 2011 onwards have experienced a confluence of factors that have exerted a negative impact on rice production and consumption patterns. These factors include a slowdown in productivity, and adverse climatic conditions. Additionally, shifts in dietary patterns, partly due to the rising incidence of Type II Diabetes, have further altered the demand-supply dynamics for rice. Rice is notably water-intensive, requiring between 1000-5000 liters of clean water per kilogram of rice produced. This significant water footprint has led to rice being categorized more as a resource-intensive crop.

In the context of India, rice is grown on approximately 43.86 million hectares, with an annual production level of 104.80 million tonnes and a productivity rate of around 2390 kg/ha. Despite being cultivated under diverse soil and climatic conditions, the productivity level of rice in India remains relatively low compared to several other countries. For instance, China boasts the highest productivity at 6710 kg/ha, followed by Vietnam with 5573 kg/ha, Indonesia with 5152 kg/ha, and Bangladesh with 4375 kg/ha.

The disparity in productivity levels can be attributed to several factors, including variations in agricultural practices, access to technology, and the implementation of effective irrigation systems. Moreover, the impact of climate change, characterized by unpredictable weather patterns and extreme climatic events, further complicates the agricultural landscape, making

it imperative to adopt resilient and sustainable farming practices to ensure food security. Overall, the complex interplay of environmental, economic, and health-related factors continues to shape the global rice production and consumption landscape, necessitating a multi-faceted approach to address the challenges and sustain the vital role of rice in global food systems.

A literature review based bibliometric model has been proposed, which will be followed by detailed analysis. This comprehensive approach aims to provide a detailed understanding of the effectiveness of sustainable rice cultivation practices currently being implemented in India. We found interesting outcome during this analysis. The System of Rice Intensification (SRI) is an advanced method that increases rice yields while reducing environmental impacts. Key features include minimized water use through alternate wetting and drying, enhanced soil and root systems, improved nutrient availability, and reduced methane emissions. SRI boosted Indian rice production by over 40% between 2015 and 2019. Also, it assisted in promoting sustainability, and improving soil health. However, challenges include the need for reliable irrigation, financial constraints for farmers, and certain soil conditions. Despite these challenges, SRI shows that high yields and efficient resource use are achievable, offering a sustainable solution for rice cultivation.

The outcomes include a better understanding of the most effective sustainable practices, policy recommendations for promoting sustainable intensification, and insights into better managing water usage and GHG emissions in rice production in India.

Keywords

Sustainable Intensification, Water Footprint, Rice Cultivation.

Presenter Profile

Bikramaditya Ghosh is an Erasmus+ Professor of Finance and Analytics. He has a proven track record in publication with several noted articles to his credit. His research areas are Agri Finance, Climate Finance, Green Finance & Financial Econometrics.

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Animal feed production in the context of global food security

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Extended Abstract

During the period 1995 to 2050, the world's population is projected to increase by some 72%, from 5,700 to 9,800 million people (FAO, 2024). Notably, millions of people globally, particularly young children, already suffer from inadequate protein intake due to food insecurity. The consequences of protein deficiency and malnutrition vary in severity, ranging from stunted growth and muscle loss to weakened immunity, deterioration of the heart and respiratory systems, and even death.

The National Academy of Medicine (USA) recommends that adults consume at least 0.8 grams of protein per kilogram of body weight daily, which is equivalent to just over 7 grams of protein for every 20 pounds of body weight (NAM, 2005). The United Nations has reported that food production from plants and animals will need to increase by 60% by 2050 (José Graziano Da Silva, 2012). Animal feed industry plays an important role in the food chain and therefore in satisfying people with the necessary food products, like meat, fish, dairy products and eggs. According to the 2024 Agri-Food Outlook, Global animal feed production remained steady in 2023 at 1.29 billion metric tons, a slight decrease of 140,000 metric tons from 2022's estimates (Agri-Food Outlook2024).

Based on data collected by FEFAC (European Feed Manufacturers' Federation), industrial compound feed production within the EU27 is expected to decrease in 2024 by 0.3% compared to 2023, to 147 million tons. Poultry feed production is the only sector showing growth prospects in 2024, with an anticipated increase of 1.6%. This recovery comes after a challenging 2023, marked by improved poultry production in several key member states. Countries like Italy, France, and Spain have already seen some recovery from the impacts of Avian Influenza during 2023 (FEFAC, 2024).

The UK Department for Environment, Food and Rural Affairs (DEFRA) reported that the overall pig population in the UK decreased by more than 10% between June 2022 and the same month last year. Pig feed production totaled 962.8 Kt, down 3.7% compared to a year ago (Ruud Peijs, 2024). One significant cause was the war in Ukraine. Russia leads the world in exporting wheat and fertilizers, while Ukraine is the largest exporter of sunflower oil and the fourth largest exporter of corn. From 2015 to 2020, their combined export market shares were 28% for wheat, 15% for corn, 66% for sunflower oil, and 16% for fertilizers (Thomas Glauben, 2022). The surge in grain prices throughout 2022 rapidly led to higher compound feed costs, causing notable affordability challenges for the animal sectors. As a result, livestock numbers were cut back, leading to a decrease in feed demand (AHDB, 2024). Russia's war in Ukraine has resulted in the most significant military-related disruption to global agricultural markets in at least a century. It has caused challenges for European feed producers, including raw materials shortages, high feed prices and energy costs, and supply chain disruptions (Thomas Glauben, 2022).

This war continues. Analysis by NASA Harvest, NASA's Global Food Security and Agriculture Consortium, estimates that the amount of abandoned cropland in Ukraine in 2023 due to the war is equivalent to about 7.5%of total cropland in the country. This has a significant influence on the EU and the world food market (Caitlin Welsh, 2024).

The EU is mostly dependent on the import of high protein content (30-50% protein content) feed sources (72%), mainly co-products (61%) sourced from Third Countries from crops not grown significantly in the EU (soybean meals, linseed meal, palm kernel expeller, etc.) (FEFAC, 2023). The immediate loss of such important animal feed ingredients like feed maize, sunflower meal and other feed materials from Ukraine and Russia could only be partially compensated by increased feed imports, mainly from the U.S. and Canada (Ann Reus, 2022). The war in Ukraine not only led to a surge in costs and volatility in the availability of macro ingredients but also highlighted the sensitivity and dependence of global food production supply chains. All these together with animal diseases — namely African Swine Fever (ASF) and Avian Influenza (AI) created many problems in the animal industry during these years.

Although raw material costs remain a major concern, producers are exploring innovative feed additives, adopting antibiotic reduction strategies, tackling production challenges and High energy and transportation costs (Poultry Nutrition & Feed Survey, 2024). The main challenge the livestock industry is facing in north-western Europe, is how to continue to produce sufficient, high-quality animal protein to feed the growing global population and at the same time to reduce the impacts on the environment and climate. More projects use Life-Cycle Assessment (LCA) methods and methane emission as an important indicator of raw ingredients / animal feed assessment.

It is now the time to advance animal nutrition solutions to assist farmers in addressing various challenges, including reducing the need for antimicrobials, enhancing animal welfare, and implementing nutrition or ingredient-based strategies to mitigate livestock emissions such as methane. In order to expand protein sources in the animal feed industry, there are numerous studies relating to novel protein sources, which may represent the new alternative animal feeds of the future, like single cell protein, insects and worm meal etc.

ASF and AI have affected animal agriculture across Europe for many years, so biosecurity protocols were strengthened. EU biosecurity measures were quite successful in containing the expansion of African swine fever, but avian influenza was much more difficult to control.

According Alltech's survey, various technologies are creating growth opportunities for the agri-food industry. Among the technologies having the most significant impact are nutritional solutions, biosecurity measures, and labour automation/robotics. Within nutritional solutions, respondents highlighted enzymes (32%), technologies affecting rumen function (14%), and mycotoxin management (14%) as the most crucial to their market (Agri-Food Outlook, 2024). One of the promising technologies is digitalization, it will increasingly continue to be applied to animal agriculture to reach the industry's sustainability goals committed to working towards a circular approach to agriculture that retains as many nutrients as possible within the food chain.

Keywords

Animal feed production industry, animal feeds, global feed security.

Presenter Profile

Dr. Liudmyla Fihurska is an Associate Professor of the department of grain and compound feed technologies, PhD in grain science, Visiting scholar of Queen's University Belfast. Her research is supported by the British Academy. Liudmyla's main expertise is in the field of animal feed technology, grain science and her research topic focused on animal feed, grain and food processing technologies, fish feed production, testing of feed manufacturing processes and animal feed.

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Keynote: Greenhouse gases and agriculture: are we afraid of the real solutions?

Dr. Vera Eory

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Presenter Profile

Vera Eory is interested in the socio-economic aspects of sustainable agriculture and works with interdisciplinary methods to better understand how to reduce the environmental effects of agricultural production. Her research spans a variety of topics, including the cost-effectiveness of mitigation practices, farmers' perceptions and behaviours regarding practice uptake, and the development and assessment of policy instruments.

Grass derived food ingredients: Consumer Insights and Environmental Assessments from the Pasture to Plate Project

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Abstract

Sustainable food production is critical for ensuring food security and environmental protection. The Pasture to Plate project investigates the potential of grass as a novel food source by developing technologies to extract essential ingredients such as oils, proteins, and vitamins. This study examines UK consumer perceptions of grass-derived ingredients and their willingness to include these in their diets. A survey of 990 participants, categorized as meat avoiders, reducers, and consumers, highlights key factors influencing acceptance, including age, dietary habits, perceived benefits, social influences, and personal attitudes. The study emphasizes the need for consumer education to enhance acceptance by informing the public about the nutritional value, safety, and sustainability of grass-based ingredients. Additionally, an environmental impact assessment of producing 1 kg of protein powder was conducted using SimaPro 9.1.0.11 software and the ReCiPe 2016 Midpoint (E) methodology. This assessment examined impact categories such as human carcinogenic toxicity, freshwater and marine ecotoxicity, global warming, and more. To ensure accuracy, the next steps involve reconfirming mass balances, evaluating plant performance scenarios, conducting sensitivity analyses, and finalizing the Life Cycle Assessment (LCA). These efforts aim to refine environmental impact data and support the adoption of grass derived. The findings show an overall openness from respondents to trying unfamiliar foods which could indicate that grass-derived ingredients could be well received in the market. However, the findings emphasise the importance of educating consumers regarding grass-based ingredients, their nutritional benefits and safety, to enhance consumer awareness and consumer confidence. Without this education grass-derived ingredients may struggle to gain a positive reaction in the human diet.

Keywords

Grass; Food; Sustainability; Willingness To Try; Grass-Based Ingredients; Consumer Perceptions; Environmental impact assessment; Life Cycle Assessment (LCA)

Presenter Profile

Anne Mumbi is a senior post-doctoral researcher in the pasture to plate project at Harper Adams University. She has a background in environmental engineering and science and holds a PhD from the school of Economics and Management of Kochi University of Technology, Japan and a PhD in Environmental Engineering from Tongil University, China. Her key specialization areas and interests are risk management, economics, environmental science, water resources and social sciences. She is also involved in teaching research skills level 7 and economics at Harper Adams University.

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Introduction

The challenge of achieving global food security while minimizing environmental degradation has become increasingly pressing in the context of rapid population growth and climate change. According to the United Nations (UN), the world population is projected to exceed 9.8 billion by 2050 (UN, 2019), which will significantly escalate the demand for food. Meeting this demand requires innovative solutions that balance productivity with environmental stewardship (Lima et al., 2023). Conventional food production systems, heavily reliant on crop and livestock agriculture, are associated with numerous environmental concerns, including greenhouse gas emissions, deforestation, soil degradation, and excessive water usage (Foley et al., 2011).

In the United Kingdom (UK), 70% of all agricultural land is covered with substantial quantities of grass that is never fully utilized (DEFRA, 2022). At present, the only way of producing food from grass is to feed it to animals who convert it into meat or milk. As animals typically convert only 5% of the grass food fractions into meat and 10% into milk (total system efficiency) this is a very inefficient process (Garnett et al., 2015). Further, with the growing awareness of the environmental impact of conventional animal agriculture, and the demand for health and sustainable alternatives the exploration of grass-derived ingredients is gaining momentum (Lima et al., 2023). One such innovation is the concept of utilising abundant crops like grass directly as food ingredients or to produce alternative oil and grass-derived proteins herein referred to as grass-derived ingredients. The Pasture to Plate (P2P) project led by Harper Adams University (HAU) and University of Bath is investigating technology which produces food products from grass. The extraction process produces a wide range of edible food fractions including oils, proteins, essential vitamins, and carbohydrates.

The Pasture to Plate project represents a significant initiative aimed at evaluating the potential of grass-derived ingredients for sustainable food production. This project is focused on developing innovative technologies for extracting essential food components from grass and assessing their environmental and socio-economic impacts. By leveraging grass as a raw material, the project seeks to contribute to the advancement of sustainable food systems and provide insights into the viability of non-traditional food sources. A central component of the Pasture to Plate project is the environmental impact assessment of producing grass-derived protein powder. This assessment uses state-of-the-art tools and methodologies to evaluate the ecological footprint of the production process (Goedkoop et al., 2013; PRe-Sustainability, 2020).

Consumer perceptions are key when introducing new food products to the market, especially so when novel technologies are being used (Herrera and Blanco, 2011). Evidence from previous research attempting to introduce novel technologies in food production suggests that grass for human consumption may struggle to gain positive perceptions. Insights into the key factors influencing the consumers' willingness to try (WTT) and acceptance of grass-derived ingredients in food from considerations of sustainability and nutritional value to taste and cultural factors are critical. The study objectives were as follows: (1) to investigate consumers WTT grass-derived ingredients and objections to the concept of grass as a food ingredient and (2) to identify the differences in consumers WTT and acceptance of grass-derived ingredients among meat consumers, reducers and avoiders and its influencing factors, (3) to conduct a comprehensive environmental impact assessment: through the evaluation of the environmental impacts of producing 1 kg of protein powder from grass.

Methods

Data Collection and Inventory

Data was collected through a survey consisting of distinct sets of questions and statements that aligned with the objectives of the study and developed from previous literature reviews

and existing work on novel foods (Barcellos et al., 2009; de Koning et al., 2020; Gómez-Luciano et al., 2019). UK participants were recruited through online access panels (Cint and TGM), who were also responsible for a financial compensation for the participants. Quotas were set to reflect the most recent British census with regards to gender split and 18+ age distribution. Data for the environmental impact assessment were meticulously collected from a variety of sources, including production facilities, supplier information, and existing literature. These data inputs were then utilized within SimaPro to model the entire production process and calculate the associated environmental impacts.

LCA : Environmental Impact Assessment

The environmental impact assessment for producing 1 kg of protein powder was conducted using SimaPro 9.1.0.11 software, as part of the Pasture to Plate project. The assessment employed the ReCiPe 2016 Midpoint (E) methodology, version 1.04, with a global context for the year 2010.The Goal and Scope were defined as follows; the primary objective of the assessment was to evaluate the environmental impacts associated with the production of 1 kg of protein powder. The scope of the study encompassed all relevant stages of production, from raw material extraction to final product packaging. Various Impact categories were analyzed. The environmental impacts calculated were subsequently normalized to facilitate comparison across different impact categories. Normalization involved converting the impact results into a common unit, enhancing the understanding of their relative significance.

Scenario Analysis

To ensure the robustness of the assessment, various scenarios were analyzed. The impacts were assessed under conditions of 100% plant capacity and 70% plant capacity to understand how operational efficiency influences environmental outcomes. A sensitivity analysis was conducted to evaluate how changes in key parameters and assumptions affect the results. This analysis focused particularly on the selected databases and impact assessment methods.

Results and discussion

The sample population of 990 participants (50.2% male and 49.8% female) were divided into three groups based on their meat consumption preference: meat avoiders, meat reducers and meat consumers. The three groups exhibited somewhat high willingness to try grass-derived ingredients suggesting respondents had positive attitudes towards grass-derived ingredients despite them being novel and unfamiliar (Table 1). This finding contrasted with previous research that found that unfamiliarity resulted in an increased dislike of a food product (Herrera & Blanco, 2011). Thus, the conclusion that consumers in the UK were open to trying new and unfamiliar foods and had an interest in including grass-derived ingredients in their diets.

Among the groups, meat consumers demonstrated the greatest readiness to include grass-derived ingredients in their diets compared to meat avoiders who showed the least readiness (Table 1). They also had the highest income among the groups an indication that economic status played a key role in this finding. This finding agrees with that of Gómez-Luciano et al.

(2019) who found that the highest economic group demonstrated the highest readiness to substitute conventional meat in their diets. This was an indication that meat avoiders were less likely to try grass-derived ingredients among the three groups contrasting the study of Alae-Carew et al. (2022) who found that plant-based alternative consumption was the highest on average among low meat consumers than high meat consumers. However, as their products were readily available in the market, we cannot make similar comparisons.

To determine the differences in the WTT grass-derived ingredients among the groups a one-way ANOVA (Table 1) was used. Based on the results of the one-way ANOVA between groups, there was a statistically significant difference among the three groups ($F(2, 987) = [71.769]$, $p = 0.001$). A Bonferroni post hoc test for multiple comparisons revealed a statistically significant difference between meat consumers and meat reducers amongst the groups ($p = 0.001$, 95% C.I. = [73.08, 118.33]) and ($p = 0.001$, 95% C.I. = [50.70, 91.30]), concluding that the three groups had varying levels of intention to try grass-derived ingredients. There was no statistically significant difference between meat reducers and meat avoiders ($p=0.085$).

Table 1: Comparisons Mean Differences in Willingness to try grass-derived ingredients among groups based on meat consumption/avoidance.

Group	N	Mean±SD	Meat consumers	Meat avoiders	Meat reducers
Meat consumers	640	3.60±1.06	-	0.957*	0.710*
Meat avoiders	151	2.65±1.06	-0.957*	-	-0.247
Meat reducers	199	2.89±0.98	0.710*	0.247	-

Notes: Bonferroni F=71.769 p=0.001 *The mean difference is significant at the 0.05 level. A 5-point Likert scale was used to measure willingness to try grass-derived ingredients with the medium score of 3.

The results of Pearson's correlation analysis (Table 2) revealed that the variables were positively correlated with one another. The Bartlett's test of sphericity and the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy analysis revealed high correlations amongst the variables (KMO = 0.855, Bartlett's test of sphericity = 4365.120, df = 10 and $p = 0.001$). The sampling is deemed adequate if the KMO value is larger than 0.6 and above (Field, 2013). Therefore, these variables could be used to analyse willingness to try grass-derived ingredients and indicate a degree of intention to try the foods.

Table 2: Pearsons's correlation of the dependent variable willingness to try grass-derived foods and ingredients.

		Correlations of the dependent variable				
		1	**2**	**3**	**4**	**5**
1	Eat/try foods containing grass-derived ingredients	1				
2	Buy foods containing grass-derived ingredients	0.861**	1			
3	Pay more for foods that contain grass-derived ingredients	0.631**	0.710**	1		
4	Encourage others/serve food that contains grass-derived ingredients	0.716**	0.791**	0.817**	1	
5	I would be prepared to consume foods with grass-derived ingredients	0.734**	0.748**	0.613**	0.687**	1

** Correlation is significant at the 0.01 level (2-tailed).

Environmental assessments and Impact Categories

The focus of this study was to conduct a comprehensive environmental impact assessment of producing 1 kg of protein powder using the SimaPro 9.1.0.11 software, within the framework of the Pasture to Plate project. Employing the ReCiPe 2016 Midpoint (E) methodology, the analysis provided insights into various environmental impact categories and highlighted critical areas for improvement. The assessment revealed significant impacts across several categories, with human carcinogenic toxicity, freshwater ecotoxicity, and marine ecotoxicity being particularly notable. Human carcinogenic toxicity, measured at 65.49001926 units, indicates a substantial impact on human health, which could be attributed to the production processes and raw material extraction involved in protein powder manufacturing. This finding underscores the need for adopting cleaner technologies and reducing harmful emissions throughout the production cycle.

Freshwater ecotoxicity (4.150913743 units) and marine ecotoxicity (3.408170298 units) reflect the detrimental effects on aquatic ecosystems. These impacts are likely due to the discharge of pollutants and runoff from agricultural activities associated with growing the feedstock for protein production. Strategies such as improved waste management practices and the use of environmentally friendly inputs can mitigate these impacts, contributing to healthier aquatic environments. One of the most critical categories assessed was global warming potential, which remains a significant concern in any industrial production process. The findings highlight the carbon footprint associated with protein powder production, emphasizing the need for reducing greenhouse gas emissions. This can be achieved through energy-efficient production methods, renewable energy integration, and optimizing transportation logistics to minimize emissions.

The impact on stratospheric ozone depletion and ionizing radiation were also evaluated. Stratospheric ozone depletion affects the Earth's protective ozone layer, leading to increased ultraviolet radiation reaching the surface, which can have severe health and environmental consequences. The production process's contribution to ozone depletion necessitates a re-evaluation of chemical usage and emissions control to prevent harmful substances from reaching the atmosphere. Ionizing radiation impact, while less discussed in food production contexts, is crucial for understanding the broader environmental implications. This impact category involves the release of radioactive substances, which can occur during the extraction of raw materials or energy production. Ensuring that the production processes are free from radioactive contamination and using alternative, cleaner energy sources can help mitigate this impact.

Improving the environmental performance of protein powder production involves several strategic actions. First, optimizing the production process to reduce emissions and waste is essential. This can be achieved through technological advancements, such as more efficient extraction methods and the use of cleaner energy sources. Second, implementing sustainable agricultural practices for growing the feedstock is crucial. This includes reducing the use of synthetic fertilizers and pesticides, adopting crop rotation, and practicing soil conservation techniques. These measures not only minimize environmental impacts but also enhance the sustainability of the agricultural system. Third, waste management practices need to be improved to prevent pollution and promote resource recovery. For instance, using by-products and waste materials from the production process as inputs for other industries can create a circular economy, reducing the overall environmental footprint.

Future Directions and limitations of the study

Future research should focus on several key areas to build upon these findings. Long-term studies assessing the ecological impacts of large-scale grass cultivation, socio-economic benefits for local communities, and consumer acceptance in diverse regions will provide a more comprehensive understanding of grass-derived ingredients' potential. Technological innovations and policy development will also play crucial roles in optimizing production processes and enhancing sustainability. This study has several limitations that should be considered. The survey sample of 990 participants may not fully represent the broader UK population, potentially affecting the generalizability of consumer acceptance findings. The use of self-reported data may introduce social desirability bias, influencing the accuracy of attitudes towards grass-derived ingredients. Economic factors, including pricing and accessibility, were not directly assessed, which could impact adoption rates. The environmental impact assessment used data from 2010 and focused on specific impact categories, possibly overlooking other environmental effects and advancements in technology. Future research should address these limitations by including diverse samples, considering economic barriers, updating impact assessments, and exploring long-term consumer behaviour and market dynamics.

Conclusion

The findings contribute to the broader discourse on sustainable food production and the potential of non-traditional food sources like grass-derived ingredients. The analysis defined by the ReCiPe methodology covered a broad spectrum of environmental impact categories, providing normalized impact values for each. Significant impact categories included: Human Carcinogenic Toxicity: 65.49001926 units, Freshwater Ecotoxicity: 4.150913743 units, Marine Ecotoxicity: 3.408170298 units. Further, the study presents insights into the acceptance of grass-derived ingredients in consumers' diets. Results show an overall openness from respondents to trying unfamiliar foods which could indicate that grass-derived ingredients could be well received in the market. Further, in the interest of sustainability, this finding can help promote other food products that are developed in a sustainable manner such as alternative proteins. The positive findings are important because research shows that encouraging people to try a novel food product for the first time is one of the biggest challenges when introducing new, unfamiliar food technologies.

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Biochar and circular agricultural systems: an application to Viticulture production system

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Extended Abstract

Biochar is a carbon-rich product resulting from the pyrolysis combustion of biomass, which has the ability of both trapping soil carbon and improving its properties, mainly by preventing erosion and water draining. It has also the ability to restore essential organic matter lost with the removal of biomass from agricultural systems. Biochar has been experienced from a long time by Amazonian communities, allowing to preserve their soil by the *terra preta* ancestral practices. Moreover, as it can be produced by burning biomass wastes, it can contribute to the promote circular agroeconomic systems. It can also give another source of income to the agricultural sector by providing a supplementary energy source and soil amendment through its production of heat and of bio-oil by- products.

Biochar techniques have been experienced in various contexts, using different pyrolysis techniques and biomass inputs (mainly, waste and agricultural residues), on different soils and in different agricultural contexts. The aim of this paper is (i) to evaluate the economic feasibility of Biochar and its different advantages, which go far beyond its direct valuation through current techno-economic analysis, (ii) to assess its ability to promote circular economy at different farm levels (iii) to present a project, the REVIVFI project, launched in the French Centre Val de Loire region, which proposes to implement Biochar production and use in vineyard, in order to remediate long term soil pollution by the Bordeaux mixture.

(i) A literature survey on Biochar exhibits a huge diversity of results, related to the production technique of biochar, the nature of the soils on which it is used, and the different technical configurations implemented, slow pyrolysis being the most widely used.

For the use of Biochar as an agricultural soil improver, its benefits are highly dependent on the nature of the soils concerned: while Biochar's ability to improve the soil's capacity to retain moisture and nutrients is undeniable, this capacity mainly concerns degraded soils.

The benefits of adopting Biochar as a soil amendment go farther than its only direct agricultural gains. They have to be calculated over a long-term scale, as its ability to sequester carbon in the soil persists over a long time. This property allows it to be considered as a powerful Carbon Dioxid Removal (CDR) technique. Another benefit lies in its ability to prevent water erosion, pollutant infiltration (mainly, Nitrogen) and fertilizer persistence in the soil. Biochar appears as a powerful tool to improve soil quality at a low cost, jointly with improved seed varieties and SWC (Soil and Water Conservation) techniques.,All these benefits are difficult to evaluate, but are necessary to realize a comprehensive cost/benefits analysis of biochar.

(ii) The economic and environmental benefits of Biochar are mainly depending on whether it is produced locally, on a scale that can vary, or purchased from external suppliers.

Their economic valuation needs also to take account of its contribution to a circular economy scheme, at various scale, from farm small production units to large-scale industrial units using urban wastes. The economic balance of different projects depends highly on their ability to be included in local circular economy networks. A large number of studies are devoted to various configurations where biochar is produced locally, mainly from agricultural waste, in units of varying size, with recovery of the heat produced by combustion to meet the needs of the farm, and optimization of the fertilizers and biochar composition. More specific uses for biochar have also to be considered, notably for the polluted or degraded land remediation as the REVIVIFI case study. Then considering a circular economy approach improves the cost/benefit balance of biochar and will make it a decisive factor in the search for new agro-ecological practices.

(iii) The REVIVIFI regional project lies in a case study on the implementation of biochar production using vineyard wastes (vine shoots, grape marc, other wastes). Biochar will be incorporated in the soil and then will fix copper residues incorporated in the soil after years of Bordeaux mixture use. Moreover, the biochar pyrolysis burning produces bio-oil by-products, which can be used as soil amendment, improving its ability to fix copper. The REVIVFI Project will assess the gains linked to the use of Biochar use in vineyard, in different soils and landscape contexts, from an agronomic and an economic point of view.

Keywords

Circular economy; agroecology, Carbon dioxin removal, polluted soil remediation.

Presenter Profile

Xavier Galiègue is associated professor at the Laboratory of Economics of Orléans (LEO), University of Orléans, and is working on various issues linked to Energy transition, Climate change economics, and Agroeconomic Valuation.

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Mapping the intellectual structure and trends in subjective well-being and climate change in agriculture: A biblio-thematic analysis

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Abstract

This study investigates the interconnections between subjective well-being (SWB), climate change and agriculture through a bibliometric analysis of 3107 publications from 1998 to 2024. The research reveals a growing body of literature on this topic, yet a significant research gap exists in exploring the intricate relationships between these domains, for which thematic analysis was conducted. The study uncovers a complex relationship between climate change, environmental impacts, agricultural practices, and subjective well-being by mapping the intellectual structure and identifying key trends. Bibliometric analysis uncovered influential sources (Sustainability), writers (Whitmee with co-authors) and nations (China) that made substantial contributions to the subject. A proposed relational framework highlights the multifaceted effects of climate change on SWB, mediated by factors such as health, stress, technology, soil health and water availability. The findings emphasise the need for integrated approaches involving education, policy and mitigation strategies as moderating variables to address the challenges posed by climate change and enhance agricultural sustainability and human well-being.

Keywords

Subjective Well-being, SWB, Climate change, Agriculture, Environment, SDG

Presenter Profile

Dr Dukhabandhu Sahoo has expertise and specialisation in the field of Economics, with more than two decades of extensive research and teaching experience in Applied Econometrics, Industrial Economics, Environmental Economics, Development Economics and Social Sector Economics with Public Policy. He also specialises in Program Management, Coordination, Research, Consultancy, Market Surveys and Data Management (design, collection, analysis and presentation). Dr Sahoo has in-depth experience in estimation and forecasting through econometric models for quantitative and qualitative variables, as well as in the interpretation and presentation of policy and research reports, journal articles and books.

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Introduction

It is not uncommon for there to be an excessive quantity of scientific literature on a single topic (van Nunen et al., 2018), and this number continues to expand. As a result, it is difficult for scientists to have a systematic perspective on the material that is vital to them. Bibliometrics is an excellent technique for doing a literature review because it has the ability to effectively disclose the most recent advancements in a particular area of study (Wang et al., 2014), which is used in this study. The combination of climate change, agriculture and Subjective Well-Being (SWB) indicates an important research field emphasising the direct and extensive effects of climatic alterations on human well-being and societal advancement (Dorner et al., 2024; Rahman et al., 2023; Dorji et al., 2023). Climate change greatly influences agricultural systems in various ways, resulting in environmental and socio-economic impacts. These effects, therefore, indirectly impact SWB by modifying food security, health status, and economic conditions (Bai et al., 2022; Fischer et al., 2005). Hence, although substantial research activity exists in this general area, there is still a lack of methodologically rigorous explorations of the intellectual landscape and developing trends within this broadly defined, multi-disciplinary research domain. Therefore, this study suggests a biblio-thematic analysis to understand how climate change and agriculture relate to SWB, the dominant themes, the factors influencing the relationship and the existing research gaps. In line with bibliometric analysis To this end, through mapping of co-citation, keyword and topic analysis, this research seeks to identify core themes, key researchers and gaps in the interactions between subjective well-being, climate change and agriculture that would foster improved humanistic approaches to climate change adaptation and mitigation strategies in the agriculture sector. On that basis, thematic analysis has been used to develop a model that has been put forward in an attempt to provide a more holistic perspective of how all these elements enfold and contribute towards the desired outcomes in agriculture and human livelihoods under changing climate conditions.

The major objective of this bibliometric research is to investigate current literature on SWB, climate change and agriculture published between 1998 and 2024. Consequently, the following research questions are going to be investigated in this study to find the answers to them: (1) Between 1998 and 2024, what is the anticipated publication pattern for SWB and climate change in agricultural settings?; (2) Looking over 1998–2024, what words or phrases are often used in relation to the research?; (3) How have the relevant institutions, authors, or countries worked together since 1998?; (4) What kind of link exists, and how is the relationship between agriculture, climate change, SWB and other factors (such as moderating and mediating variables) analysed?

According to Muhtar et al. (2021), the outcomes of bibliometric studies provide recommendations to other researchers on how to conduct their own study. Subjective Well-Being and Climate Change in the agriculture research landscape may be better understood with the use of bibliometric analysis. The systematic analysis of the number, impact and structure of academic papers in this discipline helps uncover trends, significant contributors and emerging topics. This analysis helps policymakers, researchers, and practitioners make informed decisions and advance concepts and interventions to improve subjective well-being in agriculture that is facing climate change. The outcomes of the research will also advance several Sustainable Development Goals, which are as follows: SDG1 on No Poverty, SDG 2 on Zero Hunger, SDG 3 on Good Health and Well-Being, SDG 6 on Clean Water and Sanitation, SDG 8 on Decent Work and Economic Growth, SDG 12 on Responsible Consumption and

Production, SDG 13 on Climate Change, SDG 15 on Life on Land and SDG 17 partnership for the Goals.

Theoretical Underpinning

Social-ecological systems (SES) theory is a suitable framework for examining different relations between people and their natural environment, especially in interdisciplinary contexts, such as agriculture's relation to subjective well-being and climate change. SES theory suggests the world's inhabitants, including planet Earth, human beings and all living organisms, form a cycle where a change in any part of the cycle will automatically influence the other part of it (Ostrom, 2009; Ostrom and Cox, 2010; Petrosillo et al., 2015). This interconnectedness can also be seen in agriculture, where farming practices and land use influence functions and processes of the ecosystem, such as soil fertility and water availability, whereby crop productivity and farming profitability are also affected (Garbach et al., 2014; Pimentel and Burgess, 2013; Kanianska, 2016; Albou et al., 2024). Objective quality of life, as well as self-perceived satisfaction with life, known as the subjective well-being of the people, is affected by these agricultural practices (Badowska and Szkultecka-Dębek, 2023; Ji et al., 2023; Yakubu and Aidoo, 2015). Consistent farming practices and healthy cropland (sustainable) can enhance the well-being of society through food security, limited pollution and increased stability (Jiva, 2023). Climate change complicates this scenario by modifying climatic characteristics that may negatively impact agricultural yields and natural ecosystems, thus leading to reduced levels of perceived happiness because of stress, fluctuating economic rates and ailments that arise from the condition (Malhi et al., 2021; Weiskopf et al., 2020; Padhy et al., 2015; Rahman et al., 2022). Hence, SES theory highlights the importance of solving these issues, taking into account human and ecological aspects and calling for the implementation of adaptive management goals that will build up SES resilience, sustainability and integration.

Methods

The evaluation of bibliographic resources through the use of quantitative approaches is a beneficial application of bibliometric analysis. According to Cancino et al. (2017), the approach gained popularity as a means of representing the summarised findings of categorised bibliographies. According to Aparicio et al. (2019), the term "bibliometric analysis" indicates that it is "a part of scientometrics for utilising mathematical and statistical methods to analyse scientific activities in a research field." Present researchers all around the globe are using this cutting-edge approach to better comprehend the rising patterns in specific knowledge fields. This study utilises the open-access freeware VOSviewer (version 1.6.20) to conduct a bibliometric analysis. The program is used to generate, visualise and investigate the bibliographic data for this research. Researchers are required to carry out a number of stages to complete the approach. Per the research protocol, these stages are pre-established, and all potential sources of error (or bias) that can undermine the study's significance are considered (Pedro et al., 2018). Figure 1 shows the steps in this study's research methodology. Following bibliometric analysis, a theoretical framework based on a thematic literature review on climate change, SWB and agriculture has been proposed. Thematic approach analyses all kinds of information-bearing sources, such as published and unpublished articles, publications, conference proceedings, reports and texts (CGAP, 2022; NHS England, 2022). This retrieval of literature was further improved to understand the research area better as it featured some of the often rare sources.

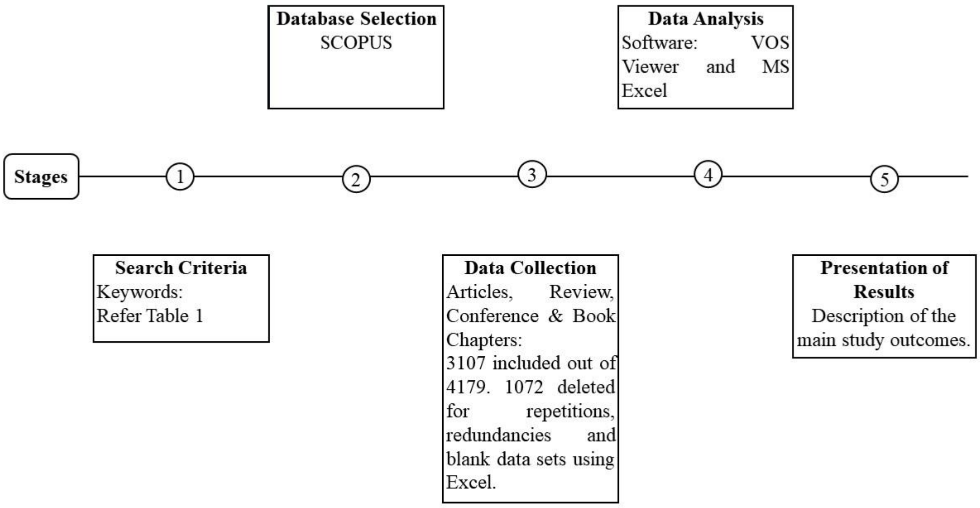


Figure 1: Five bibliometric analysis stages.

Search Criteria

As a preliminary requirement, the research has to be based on scholarly publications that examine SWB and climate change in agriculture. Several factors were considered while using this keyword criterion. The primary objective was to verify that this work could adequately cover the scholarly literature. The second objective was to keep the focus of the investigation on the original research topics. Therefore, as seen in Table 1, many synonyms were used alongside the primary keywords. The search for all of these terms was conducted using double quotation marks, which tell the database to return results, including the precise sequence of words entered. For this purpose, we searched the whole content, including the title, abstract, keywords and text (Jain et al., 2022).

Table 1: Keyword search criteria used for data extraction.

Keywords (All Fields of Scopus Database)					Extracted	Date
"Subjective Well-being"					973	
"Subjective Well-being"					261	
"SWB"					121	
"Happiness"					1516	
"Life Satisfaction"					632	
"Emotional Well-being"	and	"Climate Change"	and	"Agriculture"	132	15-07-2024
"Emotional Well-being"					50	
"Psychological Well-being"					354	
"Psychological Well-being"					68	
"Positive Mental Health"					38	
"Perceived Well-being"					21	
"Perceived Well-being"					13	
Total					**4179**	

Database Selection

An extensive literature search was conducted as part of this research using SCOPUS, a leading scientific database that is well-known for its usefulness in academic citation analysis. Searching for and evaluating relevant research material is made much easier using SCOPUS, an interdisciplinary platform that indexes the most referenced journals across several domains (Zhu and Liu, 2020; Liu et al., 2014; Liu et al., 2012). Each article indexed in SCOPUS contains a multitude of specific information, including the year of publication, the names of the authors, their affiliations, the title of the publication, an abstract summarising its content, the journal in which it was published and a list of references cited (Schotten et al., 2017).

Data Collection

The search was conducted on July 15, 2020. The document comprised articles, reviews, conference papers and book chapters presenting studies on subjective well-being (SWB) and climate change in agriculture. Therefore, the document type was chosen as "Article, review, conference papers and book chapters." The designated time period was not set to get all the relevant papers. The first findings from the SCOPUS search yielded 4179 publications written in English, specifically focusing on final published papers and excluding articles in press. After completing the data search, we exported the findings in the "CSV" format, including all accessible information, for the purpose of the initial stage of analysis in Excel, followed by VOS viewer.

Data Analysis

The first step of data processing in Excel included checking 4179 papers for duplicates, blanks and redundancy; 1072 were eliminated. A total of 3107 papers were included in the final analysis, which was carried out using the VOSviewer software. Following the gathering of data, the selected papers were evaluated by considering the streams that were selected before the data synthesis was performed. An analysis was performed on the primary concepts found in the identified texts, and the connection of these concepts to the SWB and climate change in agriculture was investigated.

A technique for visualising and investigating the connections between bibliographic data entries and bibliometric network analysis was used for quantitative data analysis. Building and visualising these networks using the open-source VOSviewer software allowed us to use the method described by van Eck and Waltman (2017) and identify trends, patterns and important stakeholders in the area of study. The VOS viewer program makes it easier to see the big picture in search results by creating two-dimensional maps showing links between authors, nations, keywords, co-occurrence, citations and bibliographic coupling (van Nunen et al., 2018; Cancino et al., 2017; Gall et al., 2015). According to van Eck and Waltman (2017), the clustering approach was used to find several clusters, with each group exhibiting a distinct colour variation. Papers that met a certain co-citation criterion were considered for inclusion in the clusters. According to van Nunen et al. (2018), the following is the general interpretation of visualisation: larger circles indicate more occurrences, closer distances between circles show more similarity and relatedness, and various colours indicate distinct clusters.

Bibliographic coupling is defined by Cancino et al. (2017) as the linking of two publications that use the same third article in their citations. One way to find out whether two papers are on comparable topics is to utilise co-citation. At the same time, co-authorship indicates how closely the most prolific sources are co-authored with one another. How comparable two variables are in terms of citations is the main subject of citation analysis. The most prevalent keywords are shown by the co-occurrence of author keywords, and the keywords that appear more often in the same publications are visualised by network connections (Raan, 2014).

Presentation of Results

The next parts provide a thorough quantitative evaluation of the phenomena under investigation and the final results of the detailed data processing and analysis that preceded them. An in-depth analysis and visual depiction of the data will be presented in the "Results" section, followed by a "Discussion on findings" and "Conclusions" section that provide a deep interpretation of the study and the broad implications of the study.

Results

In this section, the authors tried to find the answers and discuss the research questions RQ1, RQ2 and RQ3.

The Number of Publications and Their Growth Trend

For a long time, the quantity of scholarly articles published has been a key indicator of a researcher's or field's advancement (Agarwal et al., 2016; Yokubo, 1997). During the time period under consideration, there was an uptick in publications concerning SWB, climate change and agriculture (Figure 2). The years 1998–2024 saw the publication of 3,107 scholarly papers. From 1998 to 2008, there was a very small amount of published work in the field, with a total of only one-digit counts. Except for the years 2013 and 2017, when the number of scientific articles was 32 and 81, respectively, the number of papers has increased annually since 2009. Following 2017, there was a substantial uptick in the trend of publications, which continued until 2023. There have been 441 publications so far in 2024, and that number could rise prior to the year's end. Since the fields of SWB, climate change, and agriculture are receiving increasing attention, a rise may be anticipated.

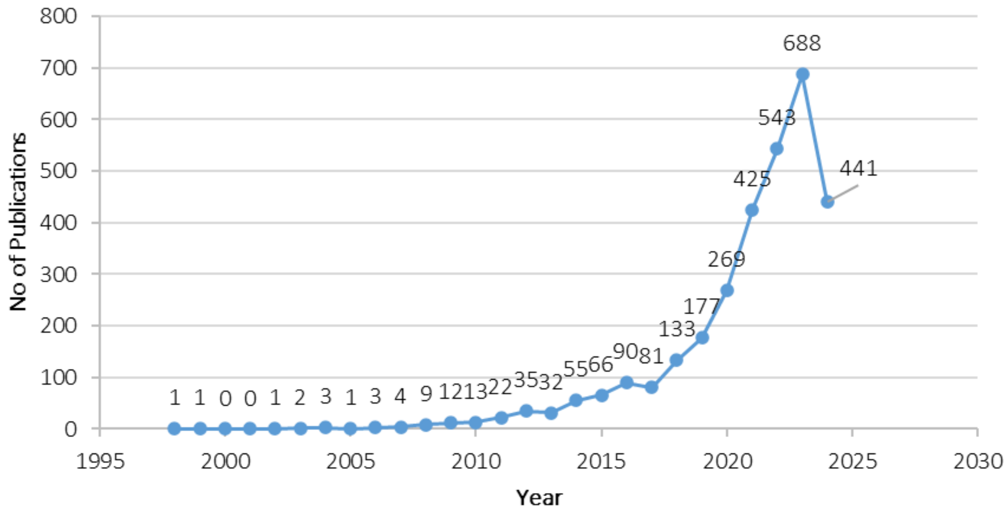


Figure 2: The number of publications related to SWB, climate change and agriculture.

Top Cited Publications

Table 2 is a list of the ten papers that have received the most citations and have had the greatest impact on studies concerning SWB and climate change in agriculture. Whitmee with co-author's "Safeguarding human health in the Anthropocene Epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health" was published in 2015 in The Lancet and received 1615 citations, with an average of 179 citations per year. This has made it the publication that has received the most citations. The article "Biodiversity conservation: Challenges beyond 2010" by Rands with co-authors, which was published in 2010 (Science) and has 846 citations, has an average of 60 citations each year. This publication is the second most referenced publication. Seven hundred thirty-seven times, with an average of 73 citations per year, the paper "A Quantitative Review of Urban Ecosystem Service Assessments: Concepts, models and Implementation" was published by Haase with co-authors in 2014 (Ambio) and is the third most referenced publication. It was published in 2014.

Table 2: Ten most cited publications in the domain.

Title	Authors	Source Title	C/Y
Safeguarding human health in the Anthropocene epoch: Report of the Rockefeller Foundation-Lancet Commission on planetary health	Whitmee S.; Haines A.; Beyrer C.; Boltz F.; Capon A.G.; De Souza Dias B.F.; Ezeh A.; Frumkin H.; Gong P.; Head P.; Horton R.; Mace G.M.; Marten R.; Myers S.S.; Nishtar S.; Osofsky S.A.; Pattanayak S.K.; Pongsiri M.J.; Romanelli C.; Soucat A.; Vega J.; Yach D.	The Lancet	1615/2015
Biodiversity conservation: Challenges beyond 2010	Rands M.R.W.; Adams W.M.; Bennun L.; Butchart S.H.M.; Clements A.; Coomes D.; Entwistle A.; Hodge I.; Kapos V.; Scharlemann J.P.W.; Sutherland W.J.; Vira B.	Science	846/2010
A quantitative review of urban ecosystem service assessments: Concepts, models and implementation	Haase D.; Larondelle N.; Andersson E.; Artmann M.; Borgström S.; Breuste J.; Gomez-Baggethun E.; Gren A.; Hamstead Z.; Hansen R.; Kabisch N.; Kremer P.; Langemeyer J.; Rall E.L.; McPhearson T.; Pauleit S.; Qureshi S.; Schwarz N.; Voigt A.; Wurster D.; Elmqvist T.	Ambio	737/2014
The economic effects of climate change	Tol RSJ.	Journal of Economic Perspectives	731/2009
Climate change and mental health: A causal pathways framework	Berry H.L.; Bowen K.; Kjellstrom T.	International Journal of Public Health	559/2010
Ecological grief as a mental health response to climate change-related loss	Cunsolo and Ellis	Nature Climate Change	548/2018
Agricultural decisions after relaxing credit and risk constraints	Karlan D.; Osei R.; Osei-Akoto I.; Udry C.	Quarterly Journal of Economics	498/2014
The 2022 report of the Lancet Countdown on	Romanello M.; Di Napoli C.; Drummond P.; Green C.; Kennard H.; Lampard P.; Scamman D.; Arnell N.; Ayeb-Karlsson S.; Ford L.B.; Belesova K.; Bowen K.; Cai W.;	The Lancet	492/2022

health and climate change: health at the mercy of fossil fuels	Callaghan M.; Campbell-Lendrum D.; Chambers J.; van Daalen K.R.; Dalin C.; Dasandi N.; Dasgupta S.; Davies M.; Dominguez-Salas P.; Dubrow R.; Ebi K.L.; Eckelman M.; Ekins P.; Escobar L.E.; Georgeson L.; Graham H.; Gunther S.H.; Hamilton I.; Hang Y.; Hänninen R.; Hartinger S.; He K.; Hess J.J.; Hsu S.-C.; Jankin S.; Jamart L.; Jay O.; Kelman I.; Kiesewetter G.; Kinney P.; Kjellstrom T.; Kniveton D.; Lee J.K.W.; Lemke B.; Liu Y.; Liu Z.; Lott M.; Batista M.L.; Lowe R.; MacGuire F.; Sewe M.O.; Martinez-Urtaza J.; Maslin M.; McAllister L.; McGushin A.; McMichael C.; Mi Z.; Milner J.; Minor K.; Minx J.C.; Mohajeri N.; Moradi-Lakeh M.; Morrissey K.; Munzert S.; Murray K.A.; Neville T.; Nilsson M.; Obradovich N.; O'Hare M.B.; Oreszczyn T.; Otto M.; Owfi F.; Pearman O.; Rabbaniha M.; Robinson E.J.Z.; Rocklöv J.; Salas R.N.; Semenza J.C.; Sherman J.D.; Shi L.; Shumake-Guillemot J.; Silbert G.; Sofiev M.; Springmann M.; Stowell J.; Tabatabaei M.; Taylor J.; Triñanes J.; Wagner F.; Wilkinson P.; Winning M.; Yglesias-González M.; Zhang S.; Gong P.; Montgomery H.; Costello A.		
Behavioural factors affecting the adoption of sustainable farming practices: A policy-oriented review	Dessart F.J.; Barreiro-Hurlé J.; Van Bavel R.	European Review of Agricultural Economics	483/2019
Consumer behaviour and demand response of tourists to climate change	Gössling S.; Scott D.; Hall C.M.; Ceron J.-P.; Dubois G.	Annals of Tourism Research	477/2012

Note. C/Y- Citation/Year of publication

Bibliographic Coupling of Publications

By counting the number of citations both articles share, a bibliographic coupling analysis may establish how closely connected they are. The number of citations is indicated by the size of the circles. At the same time, clusters are represented by colours, and distance stands for the degree to which the two publications are similar and connected. It is worth mentioning that in order to decrease the complexity's visibility, only results that match the criteria of 50 citations and above are shown. The results show 316 items organised into 13 distinct clusters (Figure 3). There are four dominant clusters. In cluster 2, the authors Rands and Haase with their co-authors have citations of 846 and 737, respectively. In cluster 8, the authors Whitmee with co-authors have citations of 1615 with the highest. In cluster 1, the authors Karlan have citations of 498. In cluster 9, the authors Tol have 731 citations.

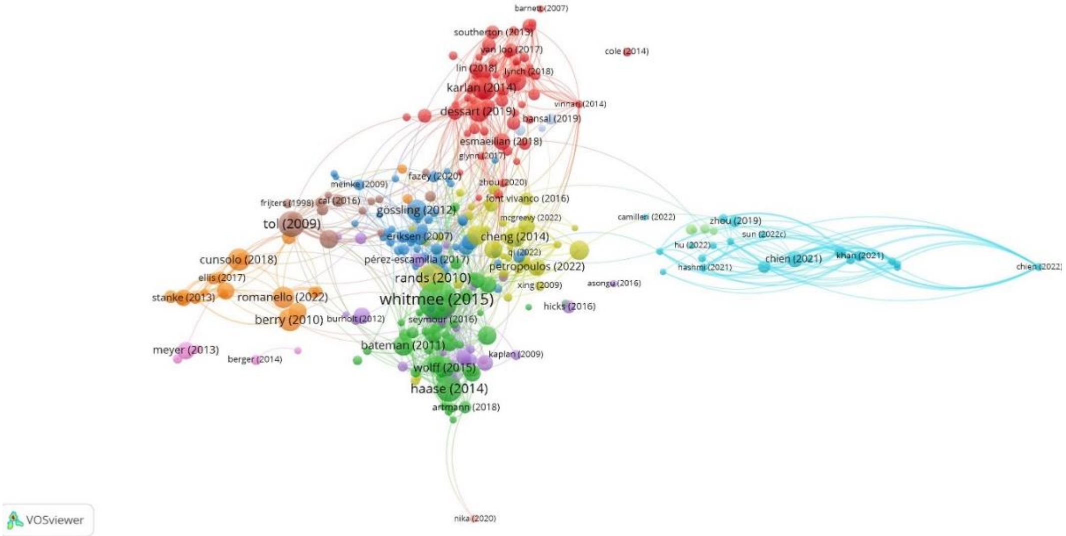


Figure 3: Bibliographic coupling of publication.

Top Cited Journals/Publishers

In Table 2, we can see a complete catalogue of the most popular and significant publications and journals in the fields of agriculture, climate change and subjective well-being. With 220 articles and 3636 citations, sustainability far surpasses all other journals in terms of citation count, resulting in an average of almost 16 citations per article. A link strength of 12914 indicates the number and quality of connections between the journal and other relevant entities (van Eck and Waltman, 2022), which is translated by this large citation count. Lancet follows closely after with a link strength of 492 and an impressive average of 471 citations per document but with a much smaller count of six. In third place, we find the Journal of Cleaner Production, which has 57 publications, 1772 citations, an average of 31 citations per publication and a link strength of 3136.

Table 3: Top ten cited journals/publishers in the domain.

Source	Documents	Citations	Total Link Strength	Avg. Citation/Document
Sustainability	220	3636	12914	16.5
The Lancet	6	2827	492	471.2
Journal of Cleaner Production	57	1772	3136	31.1
International Journal of Environmental Research and Public Health	71	1523	4135	21.5
Ecological Economics	42	1513	4090	36.0
Ecological Indicators	27	1427	1761	52.9
Global Environmental Change	16	1367	1705	85.4
Environmental Science and Pollution Research	55	1306	4436	23.7
Ambio	8	1084	756	135.5
Ecosystem Services	16	1018	3036	63.6

Co-Citation Analysis of Sources

We used a co-citation analysis, which looks at how often different journals are cited together, to determine how the journals are related (Figure 4). In this network-based visual representation, the size of each circle represents the journal's citation count, the distance between circles shows the degree of similarity and relatedness and different colours indicate different clusters (van Eck and Waltman, 2022). The journals included in this study had a co-citation frequency higher than 50. Four main clusters are visible in the resulting network: Science (with 1881 citations and a link strength of 70993) in the yellow cluster in the middle; Ecological Economics (with 1177 citations and a link strength of 47598) in the red cluster to the right; Sustainability (with 3504 citations and a link strength of 125366) in the blue cluster in the centre; and Ecol. Econ. (with 1247 citations and a link strength of 49533) in the green cluster in the bottom left quadrant.

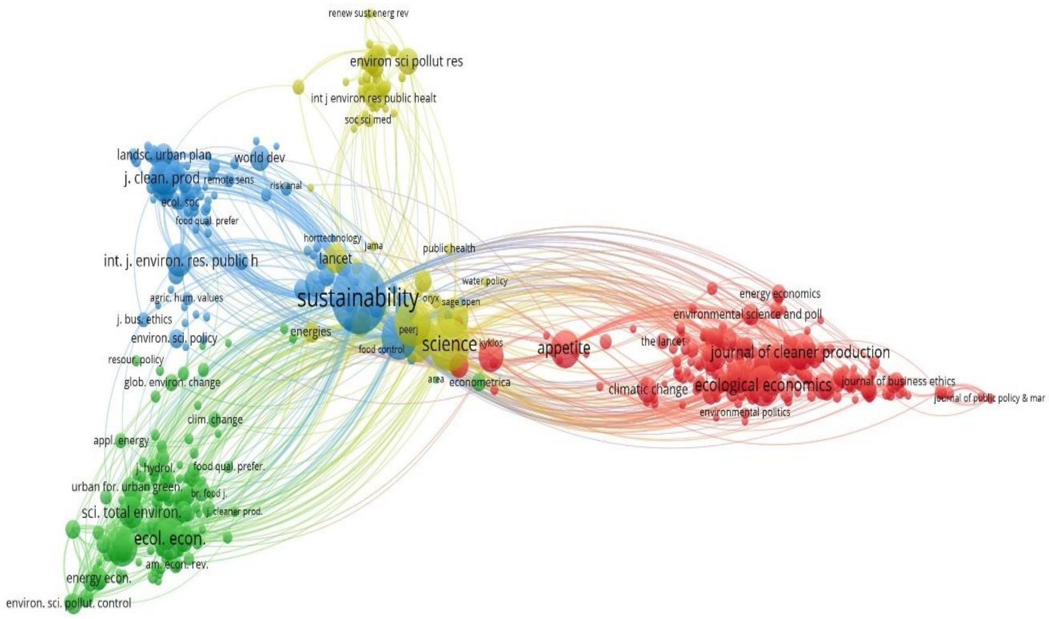


Figure 4: Co-citation analysis of sources.

Co-Citation Analysis of Authors

Figure 5 shows the results of an author co-citation study, which uses the frequency of citations to establish a relationship between the authors. A larger circle indicates a higher number of citations. According to van Eck and Waltman (2017), colours represent clusters, whereas distance indicates relatedness, similarity and collaboration among the writers. The results that fulfil the minimum requirement of 50 citations are shown. There are a total of four clusters with 1120 items: The yellow cluster belongs to Shahbaz M, who has 330 citations and a link strength of 25555; the red cluster belongs to Folke C, who has 630 citations and a link strength of 44253; the blue cluster belongs to Costanza R, who has 574 citations and a link strength of 44157; the green cluster belongs to Liu Y, who has 992 citations and a link strength of 87697; and so on.

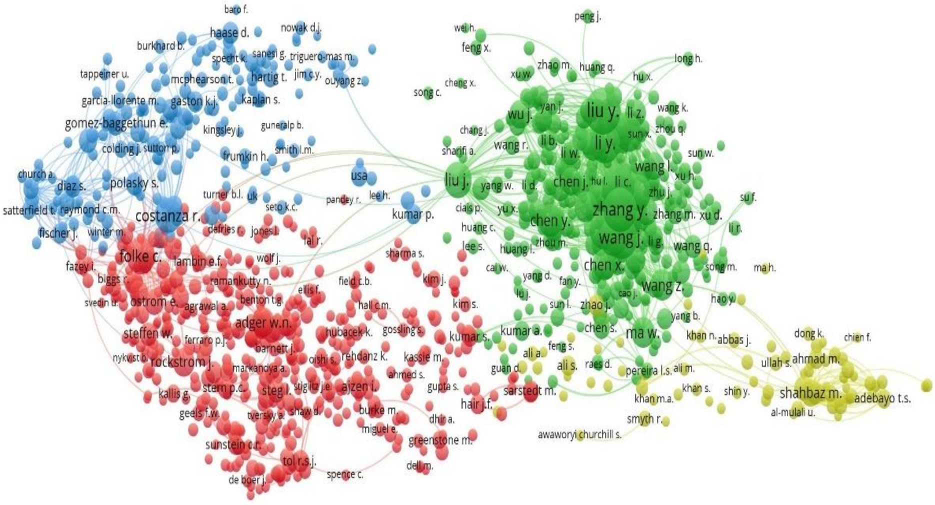


Figure 5: Co-citation analysis of authors.

Co-Authorship Analysis of Countries

As a consequence of the co-authorship research of authors, the relatedness of countries may be estimated based on the number of co-authored documents, and the degree of co-authorship between the most prolific sources may be quantified (Figure 6). The number of citations is indicated by the size of the circles. Colours indicate clusters, whereas distance indicates relatedness, similarity and cooperation among nations. In order to get the result, the threshold was established in 20 publications. In total, there are four distinct clusters that contain 51 items. The cluster in yellow, which is located in the middle, contains Australia with 11127 citations, link strength 458 and 329 documents; the cluster in green, which contains the United States with 19777 citations, link strength 759 and 615 documents, is located at the top; the cluster in red, which contains Germany with 8844 citations, link strength 494 and 231 documents, is located at the left bottom; and the cluster in light blue, which contains China with 13593 citations, link strength 541 and 633 documents, is located at the right bottom. There have been 633 publications from China, 615 from the US and 329 from Australia, making them the top three countries in terms of overall publications.

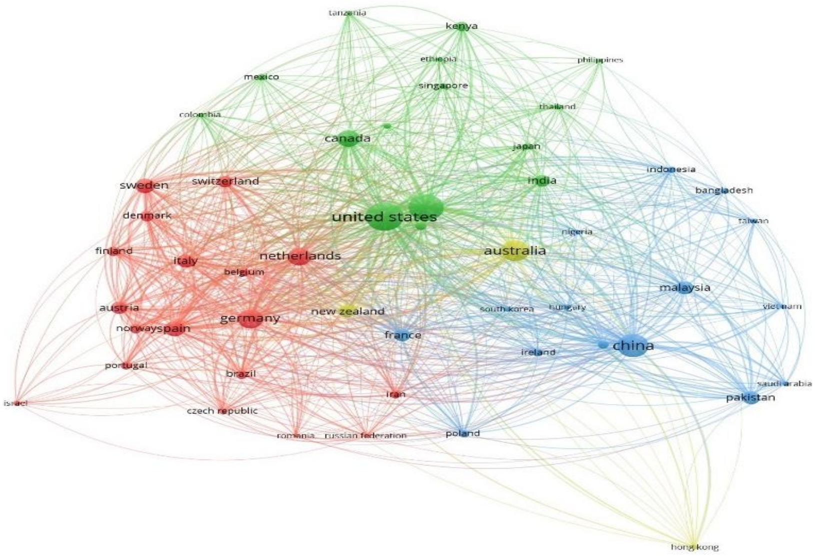


Figure 6: Co-Authorship Analysis of Countries.

Co-Occurrence of Authors' Keyword

Analysing the frequency with which writers utilised a set of keywords in different texts allows us to draw conclusions about the closeness of those keywords (Figure 7a). Clusters are represented by colours, relatedness and similarity between keywords by distance, as well as the number of keywords utilised by the size of the circles. Importantly, only outcomes that satisfy a criterion of 20 times are shown. Country names like Indonesia and China were not filtered out of the keyword analysis. With the help of Table 4, we can see that there are five distinct groups: The yellow cluster ("climate change", 266 occurrences on the left), the red cluster ("sustainability", 161 occurrences on top), the green cluster ("ecosystem service", 101 occurrences on the right bottom), the blue cluster ("well-being", 73 occurrences in the middle) and the purple cluster ("mental health", 59 occurrences on bottom). The author utilises the following keywords: climate change, sustainability, ecosystem service, well-being and mental health; they are derived from the study's outcomes. However, very few studies have been conducted on agriculture, SWB, happiness, life satisfaction and psychological well-being, whose occurrence and link strength were shallow. Here, it can also be concluded that not much research has been done in this domain of togetherness, especially on climate change, SBW and agriculture (the size of the circle of climate change and other variables can be seen in Figure 7b).

Table 4: Keywords with Underline Clusters.

Cluster 1 (11 items)	**Cluster 2 (10 items)**	**Cluster 3 (9 items)**	**Cluster 4 (6 items)**	**Cluster 5 (4 items)**
Biodiversity	Ecosystem Services	Covid-19	Adaptation	Agriculture
Conservation	Food Insecurity	Food Security	Climate Change	Farmers
Economic Growth	Green Infrastructure	Public Health	Drought	Mental Health
Environment	Human Well-being	Quality of Life	Health	Well-being
Environmental Sustainability	Nature-based Solutions	Resilience	Migration	
Gender	Poverty	Social Capital	Vulnerability	
Pro-environmental Behaviour	Sustainable development goals	Subjective Well-being		
Renewable Energy	Urban Agriculture	Sustainable Consumption		
Rural Development	Urban Planning	Well-being		
Sustainability	Urbanisation			
Sustainable Development				

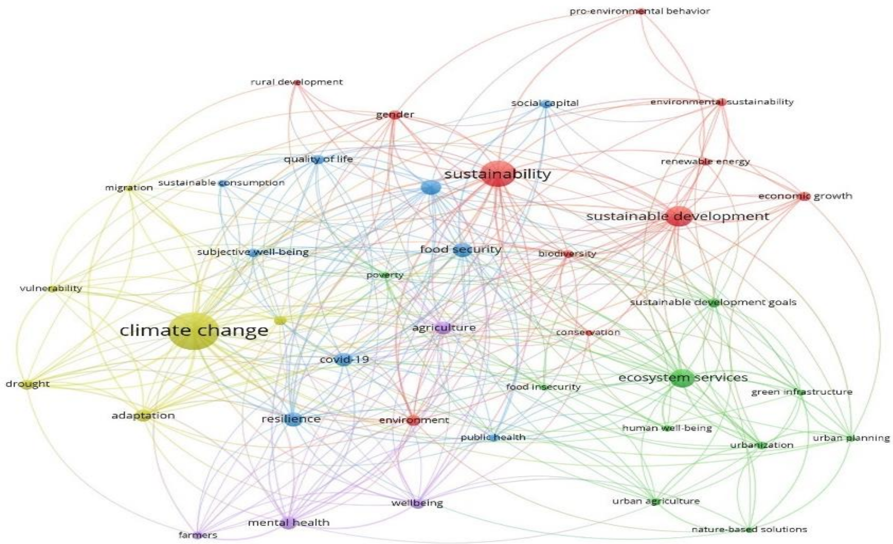


Figure 7(a): Co-occurrence of authors' keyword.

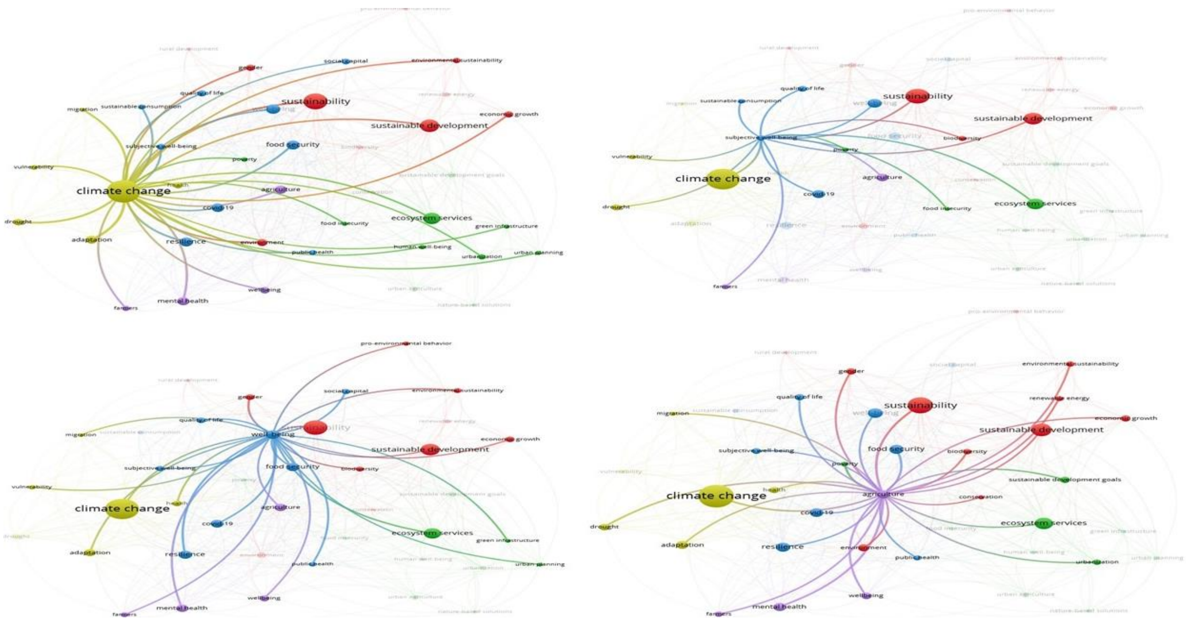


Figure 7 (b): Co-occurrence of authors keyword focusing on climate change, subjective well-being, agriculture and well-being Individually.

Discussion

The papers of interest were scientific ones related to SWB, climate change and related agriculture, published from 1998-2024 in all the fields the SCOPUS database searched for this purpose. Therefore, the study includes 3107 papers, 11617 authors, 1107 sources, 189 countries and 9227 institutions. The analysed topics are the works of academicians who strive to unify exponential growth, which has appeared over the course of the last decades. The following findings can be outlined from this study:

1. The results of the comprehensive field search revealed that there are a total of 3107 articles on the subject of SBW, climate change and agriculture. These findings provide an explanation for the growing interest in studies that are being conducted in this

sector. However, despite the trend of publications, which indicates an increase in the number of papers published each year after 2017, researchers all over the world continue to have very low levels of research productivity and interest in "SBW, climate change and agriculture" together. This is the case despite the fact that there are a number of publications that are solely focused on climate change.

2. According to Cortes-Sanchez (2020), citations are an essential component of publications since they are believed to convey the relevance of the work involved. The trend demonstrates that there has been a progressive increase in the number of citations over the course of the year, beginning in 2007, with a few exceptions making the transition from 2017 to 2024. It has been discovered that 2020 has the maximum number of citations, with 8574, while the years 2000 and 2001 have the fewest or no citations.
3. Whitmee with co-authors 's paper has received an average of 179 citations every year, making it the highest-cited publication.
4. Sustainability is the journal that has received the most citations, with a total of 3636. Additionally, sustainability is one of the few publications that has had the largest amount of co-citations, with a total of 3504.
5. The author, Liu Y., has the highest number of co-citations (n = 992).
6. China is the leading scientific publisher (Citations=13593, documents=633). Global research collaboration is extensive, with most countries connected directly or indirectly to major publishing nations.

Within the scope of this study, the power-law distribution enables us to notice that:

1. The majority of authors, which account for 91.60% of the total, are only recognised in a single publication.
2. Few writers, accounting for just 0.28% of the total number of authors, have published at least five publications. This distribution is in line with the findings of the study by van Nunen et al. (2018), who found that a small number of authors produce the vast majority of scholarly literature and that many countries and journals contribute very little compared to a much smaller number.
3. 10.5% of the 1107 sources that produced articles on the subject actually published more than five papers.
4. The percentage of nations that published more than ten documents was 35.98% across all countries of the 189 that published on a subject.
5. A total of 473 papers, which account for 15.22% of all publications, have not been referenced as of yet, whereas 139 publications, which account for 4.47% of all publications, have been cited more than 100 times.

Based on the authors' use of related keywords, seven main areas of study have been identified: mental health, climate change, agriculture, sustainability, well-being, sustainable development and ecosystems. The entire network analysis showed that these main sectors were not well or closely related to each other. In particular, the network data did not reveal many connections between agriculture, climate change and well-being based on closeness and circle size. A thematic review was carried out to get a more thorough grasp of these interdependencies and to go further into the subject.

Proposed Framework Based on Thematic Review

By using a thematic analysis, this part provides a solution to RQ4 by examining the relationship between climate change, subjective well-being and agriculture. A relational framework has been proposed (Figure 8) based on the evaluation of secondary pieces of literature. Due to the fact that the bibliometric analysis was conducted, the interaction between those factors is not obvious as a new issue of debate in the context of climate change and subjective well-being in agriculture. This is because the majority of attention was only given to climate change in other dimensions.

The direct impacts of climate change on SWB are multifaceted and pervasive. Physical health issues, mental health challenges, economic instability, social disruption, environmental degradation and the occurrence of extreme weather events all contribute to a decline in SWB (SZE and London, 2008; Dodd et al., 2023; Ebi et al., 2021; WHO, 2021; Ragavan et al., 2020). Concerns about climate change have a negative impact on the well-being of farmers (Dorner et al., 2024).

Müller (2013) considered the effect of climate change as a mixed blessing in agriculture; similarly, Gowda et al. (2018) adopted a similar opinion. Climate affects agricultural systems through temperature changes, fluctuations in precipitation and the occurrence of extreme weather conditions. Such changes can affect the production of crops, the incidence of pests and diseases and the composition of the soil. Agriculture is a climate-sensitive sector, and any changes, however slight, have a profound impact on crop output. Climate change and agriculture's relationship have been a well-established theme, as studies reviewed show that climate variability is an important determinant of agricultural output (Skendžić et al., 2021; Steven et al., 2004; Parmesan and Yohe, 2003; Luo, 2011; Enete and Amusa, 2010; Williams et al., 2019).

Agricultural practices have substantial environmental implications and vice versa. This type of farming exerts pressure on the environment through deforestation, particularly in the preparation of land for farming; overreliance on chemical fertilisers and pesticides affects soil and water quality and lacks diversity (Rohila et al., 2017; Tuomisto et al., 2017). These practices, including crop rotation, organic farming and agroforestry, help solve these effects due to their nature of improving soil health, reducing the use of chemically processed inputs and increasing the rates of biological diversity (Indira et al., 2023). The environmental impact of agriculture is bidirectional: while the adoption of agriculture affects the environment badly, a poor environmental condition can also hinder the production of agriculture.

The paper reviews the literature to show that environmental quality has an influence on SWB. Clean air, water and soil contribute to better health outcomes, which are integral to overall well-being (Silva et al., 2012). On the other hand, damaging it by polluting the environment may cause health hazards, stress and lower life satisfaction levels, which have been postulated (Ortega et al., 2021; Chang et al., 2020). Recreation and aesthetic value, as well as place identity derived from the natural environment, are equally beneficial to SWB, as reported in the years 2019 and 2024, respectively, by Chowdhury and Guo. Hence, environmental health can be said to be related to the physical and mental needs of human beings.

Livelihood, especially in the rural sector, largely depends on agriculture to feed and support the populace. It creates employment, food security and economic stability, which are the fundamentals of SWB (Mphande, 2016; Mohammadrezaei et al., 2020). To many, farming is not just a business exercise or economic necessity but a cultural and social undertaking

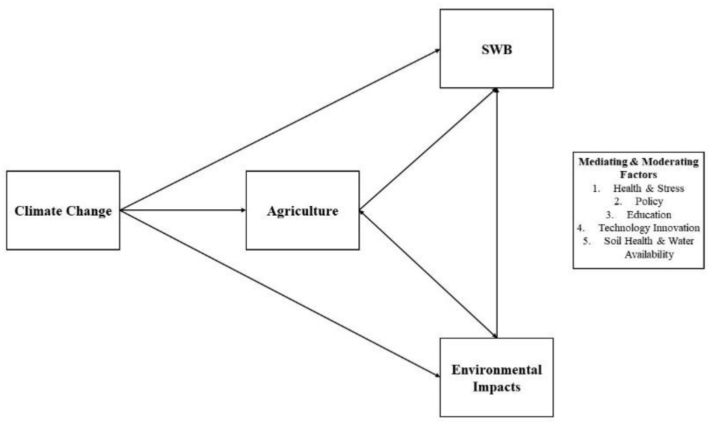
(Dudek, 2016). Due to the dependency of their products, the stability of food prices, the ability to bear climate fluctuations well and the success of their crops that affect farmers' and agricultural workers' welfare (Xiang and Gao, 2023; Me et al., 2021; Aydogdu et al., 2021). Therefore, it can be concluded that the status of agriculture determines the numerous economic and social effects received by people involved in this industry.

Climate change enhances the effects of environmental deterioration by way of frequent intense natural disasters, increasing water levels and altered ecosystems (Balbus et al., 2016; Fleming et al., 2018; Bolan et al., 2023). The aforesaid changes are direct threats to human health, safety and earnings that influence SWB. Climate change impacts other determinants of SWB in as much as it influences the availability of natural resources like water and arable land (Mahbod and Parnian, 2024).

There are many mediating and moderating factors (which can be seen in Figure 8) that could smoothen or bring rigidity to the whole process of attaining the SWB in the face of climate change. The possible mediating factors could be health, stress, technological innovation, soil health and water availability. Similarly, moderating variables could include mitigation strategies, policy and education. The effects of climate change, environmental degradation and unsustainable farming practices on human health and stress have knock-on effects on SWB (Padhy et al., 2015; Cantuaria et al., 2023; Daghagh et al., 2019). The favourable aspects of such factors may have a beneficial influence on SWB. In a similar vein, environmentally responsible agriculture methods ultimately result in technological advancements and will have a beneficial impact on the environment (Brodt et al., 2011; Brower et al., 2024; Chomsky, 2023). In addition, agriculture and poor environmental conditions both affect the availability of water and the health of the soil, which in turn affect both the environment and agriculture, respectively.

Reduced impacts of climate change on agriculture, the environment and human mental health are possible via education, policies and mitigation initiatives. Reducing emissions of greenhouse gases and increasing resilience are two goals of mitigation strategies like sustainable agriculture and renewable energy (Lberdrola, 2024; Mbah et al., 2022; UNDP, 2024). Sustainable development, stricter environmental regulations and financial incentives for environmentally friendly technology are all priorities for the government. Education raises consciousness and encourages sustainable practices by inspiring creativity and giving people the tools they need to adapt (Saikanth et al., 2023; Smith, 2023). Mitigate the consequences of climate change and enhance the general quality of life by combining these factors into a complete approach. Therefore, the following relational model (Figure 8) has been proposed to understand the interplay between the variables.

Figure 8: Proposed relational model between climate change, environmental impacts, agriculture, SWB and different moderating and mediating variables.



Conclusion

Discussing this study's flaws may help inform future research. Bibliometric analysis lowers bias in expert surveys and conventional reviews, but it has limits. Although it may overcome biases, this strategy cannot replace comprehensive content analysis and its quantitative character. This research only searched Scopus for articles. The study is nevertheless limited by Scopus, which awards one unit to each author, article, institution and country for every publication. This means that papers submitted by a single author and those submitted by several authors get equal weight in Scopus (Mukherjee et al., 2023). As databases grow and new journals are added to Scopus every day, citation numbers may change, affecting citation analysis. Citation analysis may be deceptive in this research because writers reference negative articles or self-citations. This research utilised scientific publication numbers. It is difficult to explore all the theoretical ideas in the materials. This quantitative analysis leaves the authors' field-specific theoretical knowledge, pillars and conclusions behind. Yet, a theme analysis has been included to provide a qualitative perspective. Additionally, noteworthy articles may be mentioned years later and acquire “delayed recognition” in scientific literature. Future research can address these shortcomings.

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Investigating the Relationship Between Digital Twins and Circular Economy in Indoor Vertical farming: A linguistic QFD Approach

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Abstract

This study investigates the alignment between the expected benefits of Digital Twins (DTs), as derived from existing literature, and the actual outcomes in achieving Circular Economy (CE) targets for defined Sustainable Development Goals (SDGs) in urban agriculture. Two research questions guide this inquiry: 1) To what extent do the benefits of Digital Twins (DTs) align with the targeted outcomes for achieving Circular Economy (CE) goals as defined by specific Sustainable Development Goals (SDGs) in the context of Indoor Vertical Farming (IVF)? 2)What strategies can be implemented to optimize the use of DTs in IVF systems to maximize their contribution to CE principles? A methodology integrating the Quality Function Deployment's (QFD) House of Quality (HoQ) framework with the 2-Tuple Linguistic (2TL) model is proposed to address these questions, offering a comprehensive analysis of the relationships between DT benefits and CE-related SDG targets. The study involves a case study approach with five experts, including academic researchers and modern urban farmers, who evaluate the relationships between DT benefits and CE-related SDG targets using linguistic sets tailored to their expertise. The results reveal strong relationships between DT benefits and CE-related SDG targets, particularly emphasizing the importance of optimization and automation for enhancing CE in IVF. The findings underscore the pivotal role of DT in driving sustainability and efficiency in agricultural practices, offering valuable insights for future research and practical applications aimed at advancing CE in the agri-food industry.

Keywords

Circular Economy, Digital Twin, Indoor Vertical Farming, QFD, SDGs, 2-Tuple Linguistic.

Presenter Profile

Deniz Uztürk is an Industrial Engineer (PhD) specializing in sustainability, climate change, and smart systems. As a Research Assistant at Galatasaray University, Deniz has contributed significantly to projects focused on climate change action plans and renewable energy measures for Istanbul. With a robust background in numerical methods and multi-criteria decision making, Deniz's research spans smart agriculture, sustainable buildings, and fuzzy systems. Deniz has co-authored several publications on advanced decision-making methodologies and integrated design frameworks for sustainability, highlighting a commitment to bridging the gap between digitalization and environmental resilience.

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Introduction

The landscape of food production is undergoing rapid and unprecedented transformation, driven by a multitude of challenges within the bioeconomy sector. Amidst these challenges, two prominent global issues demand urgent attention in agricultural research. Firstly, the exponential growth of the world's population necessitates the development and implementation of innovative information systems tailored to food production needs (Monteiro et al., 2023). Secondly, the ever-evolving climate patterns pose significant consequences on resource utilization, particularly water, energy consumption within vertical farm infrastructures, and the need for artificial conditions to sustain diverse food products throughout the year (Monteiro et al., 2023). Addressing the imperative task of feeding a growing global population requires the establishment of novel vertical physical structures intricately integrated with sophisticated information systems capable of autonomously monitoring and optimizing the entire production lifecycle. Indoor vertical farming (IVF) emerges as a promising solution to ensure food security for the expanding urban public while yielding various socio-economic benefits surpassing those of traditional agricultural systems. Nonetheless, the widespread adoption of IVF encounters formidable difficulties such as high energy demands, substantial capital investments, and constraints regarding the range of crop varieties suitable for cultivation (Kabir et al., 2023).

Transitioning from traditional greenhouses to high-tech 3D production spaces dispersed across urban landscapes introduces novel challenges for agriculture. The digitalization of IVFs emerges as a crucial enabler for the sustainability of urban agricultural systems. In this context, Digital Twins (DTs) emerge as a potent solution, offering three-dimensional replicas of physical objects governed by intelligent collaboration, thus paving the way for a sustainable bioeconomy transformation within agriculture (Purcell and Neubauer, 2023). The integration of IVF with DTs offers a transformative opportunity within the circular economy (CE) framework, aligning with Sustainable Development Goals (SDGs) for urban agriculture. IVF systems optimize space and resources, minimizing waste and environmental impact. DTs simulate scenarios, enabling continuous improvement in IVF processes, enhancing sustainability. This symbiotic relationship models technology-driven closed-loop systems, maximizing resource efficiency and SDG attainment in urban agriculture.

The overarching objective of this research is to investigate the alignment between the expected benefits of DTs, as derived from existing literature, and the actual outcomes in achieving CE targets for defined SDGs in urban agriculture. This objective is addressed through two research questions: 1) To what extent do the benefits of DTs align with the targeted outcomes for achieving CE goals as defined by specific SDGs in the context of IVF? 2)What strategies can be implemented to optimize the use of DTs in IVF systems to maximize their contribution to CE principles? These research questions aim to provide both qualitative and quantitative insights into the effectiveness of DTs in enhancing CE principles within IVF systems, thereby contributing to sustainable urban agriculture practices.

To address the first research question, the expected benefits of DTs are identified through a comprehensive literature review. Subsequently, based on the insights provided by the United Nations report on CE and sustainable development, SDGs and associated targets relevant to urban agriculture are selected with the guidance of expert opinion. This paper aims to develop a Quality Function Deployment (QFD) methodology (Akao and Mazur, 2003) wherein the identified DT benefits serve as Design Requirements (DRs) within the House of Quality (HoQ), while the selected SDG targets related to CE and urban agriculture constitute the Customer Needs (CNs) in the HoQ. The QFD methodology is renowned for its efficacy in designing systems or products, and it includes a relationship matrix through which the connections between CRs and DRs can be assessed. Hence, the HoQ relationship matrix facilitates an examination of these relationships and their strengths. Regarding the second research question, the QFD methodology is again employed to prioritize the DRs, which represent the benefits of DTs. This prioritization enables the ranking of DT benefits from the perspective of CE. By doing so, this paper aims to elucidate the optimal stage within IVF where DT technology can be leveraged to enhance CE principles in urban farming. Furthermore, the QFD methodology is suggested with its integration to 2-Tuple Linguistic (2TL) model to provide a more flexible assessment framework (Martínez, Rodriguez and Herrera, 2015).

The paper is organized as follows: The next section will present the theoretical background through a comprehensive literature review. Section 3 will delve into the methodological background. Section 4 will showcase a case study conducted with field experts from Turkey, along with its results and discussions. The final section will encompass the concluding remarks.

Literature Review

The literature review delves into urban agriculture and IVF, investigates DT in agricultural contexts, and explores their integration with CE principles, offering a comprehensive overview of relevant research.

Urban Agriculture and IVF

By 2050, the United Nations predicts that approximately 68% of the global population will inhabit urban areas, challenging traditional agriculture reliant on large-scale industrial methods. This urbanization contributes to environmental degradation and worsens climate change. Urban agriculture, including techniques like IVF, hydroponics, aquaponics, and rooftop gardens, offers a promising alternative for sustainable urban systems (Kabir et al., 2023). IVF, for instance, minimizes land use by cultivating crops indoors, while hydroponics uses nutrient-rich solutions for soilless plant growth. Aquaponics integrates aquaculture with hydroponic systems, fostering symbiotic relationships to optimize resource utilization. These innovative approaches mark a transition towards more sustainable urban farming practices.

When the keywords “urban agriculture” AND “vertical farming” keyword search in Scopus database (14 February 2024), we obtain 73 documents in the last five years, the 31% of these studies are published in 2022. A multitude of research endeavors have explored vertical farming (VF) across diverse domains, encompassing investigations into different types of vertical farms (Beacham, Vickers and Monaghan, 2019) , prototypes and their operational attributes (Al-Kodmany, 2018), environmental regulation and resource optimization (Vatistas, Avgoustaki and Bartzanas, 2022) , intelligent indoor farm designs, sensory technologies (Oh and Lu, 2023), consumer attitudes and reception (Gan, Soukoutou and Conroy, 2023) , as well as the potential benefits and constraints (Ragaveena, Shirly Edward and Surendran, 2021).

IVF technology is rapidly evolving, with recent advancements focusing on innovative data collection and analysis methods to optimize crop yield. These developments hold promise for improving food sustainability in urban environments and offer opportunities to benefit the environment, society, and economy. While VFs have shown potential for cultivating various crops, additional research is needed to achieve technical and economic optimization.

DT and IVF

When the “Digital Twin” AND “vertical farming” keywords are searched in the Scopus database (14 February 2023), we obtain 8 studies. One of them is published in 2024, three of them published in 2023 and other four are published, 2022, 2021, 2020 and 2018 respectively.

The most recent study by Awouda et al., (2024) introduce a thorough framework for creating and utilizing IoT-enabled DTs within the realm of Industry 5.0. It seeks to tackle the changing needs of Industry 5.0, focusing on sustainability, human-centeredness, and resilience. They also demonstrate the application of the proposed framework through a proof of concept of a monitoring DT for a VF system. The conclusions drawn by the authors underscore the substantial advantages of integrating DTs into VF systems, underscoring the potential for enhanced efficiency, sustainability, and productivity in agricultural operations.

In 2023, most of the studies focus on design and implementation of DT in VF systems. While Ahamed et al., (2023) emphasize the indoor thermal environment control with DT, Monteiro et al., (2023) and Naval, Kumar and Gaurav, (2023) suggest design models for IVFs. The reviewed literature underscores the need for further research to demonstrate the feasibility and affordability of integrating DTs into VF. While emphasizing the importance of real-time monitoring and design guidelines, challenges such as initial implementation costs and data reliability are acknowledged. Future research is expected to provide more insights into potential drawbacks and challenges associated with DT adoption in VF.

Integration of DTs with CE in Agriculture

In 2023, Boz and Martin-Ryals published a comprehensive analysis of 68 articles to explore the literature and connections between digitalization, CE, and agri-food applications. Key findings reveal that themes such as Internet of Things, Cloud Computing, and Big Data are prevalent in Industry 4.0, while Artificial Intelligence, Robotics, and Smart Manufacturing are gaining traction across industries (Boz and Martin-Ryals, 2023). Plus, the review underscores the policy, economic, and social barriers within the food industry that must be addressed to effectively digitalize the CE.

Moreover, Preut, Kopka and Clausen, (2021) introduced DT for CE. The article emphasizes the importance of digitization concepts, particularly DTs, in enhancing sustainability within the CE. Key findings highlight the critical role of accurate information management for processes like reconditioning and supply chain management. DTs enhance transparency and collaboration among stakeholders, offering economic benefits and opportunities for transitioning to circular practices. Challenges such as data protection and stakeholder willingness to share information are addressed, with digitization concepts providing solutions to enhance efficiency in material flow. Overall, these insights underscore the significant role of digitization concepts, particularly DTs, in promoting sustainability, transparency, and collaboration within the CE.

Moreover, Martindale and Lucas (2021), highlight the importance of utilizing digital techniques, including Geographic Information and DTs, to understand and optimize resource flows in the global food system. By leveraging these technologies, the paper explores opportunities to achieve sustainable outcomes, improve carbon responsibility, and enhance product assurance in food supply chains.

Recent reviews and existing literature underscore the significant potential of DTs in revolutionizing agriculture, particularly in the context of promoting a CE. This paper aims to elucidate the intricate relationship between DTs and CE within agricultural practices by employing the QFD methodology. The primary objective is to identify the most critical stage of IVF where the application of DTs can substantially enhance CE targets.

The QFD methodology, a structured approach that transforms customer needs into engineering characteristics, is pivotal in this analysis. By leveraging QFD, this study systematically maps out how the benefits of DTs, as derived from an extensive review of current literature (Table 1), align with and support specific SDGs related to CE and agriculture (Table 2). This mapping process not only clarifies the mutual advantages of integrating DTs into IVF but also highlights the stages within IVF that are most conducive to achieving CE objectives.

The significance of this research lies in its potential to provide a comprehensive framework that bridges theoretical knowledge with practical applications. By pinpointing the key IVF stages for DT implementation, this paper contributes valuable insights to the literature on sustainable agricultural practices. Furthermore, it offers actionable guidance for stakeholders in the agricultural sector, including policymakers, researchers, and practitioners, who are striving to optimize resource efficiency, reduce waste, and enhance sustainability through advanced technological integration. The findings of this study underscore the importance of DTs in fostering a resilient and sustainable agricultural ecosystem, thereby advancing the global agenda for sustainable development.

Table 1: DT Benefits.

DR#	Benefits	References
DR1	Resilience	(Pylianidis, Osinga and Athanasiadis, 2021, Naval, Kumar and Gaurav, 2023)
DR2	Adaptability	(Liu et al., 2023)
DR3	Automation	(Ko et al., 2022)
DR4	Optimization	(Ahamed et al., 2023, Purcell and Neubauer, 2023)
DR5	Management	(Ferreira, Titotto and Akkari, 2022)
DR6	Decision-support	(Naval, Kumar and Gaurav, 2023)
DR7	Prediction /Forecasting	(Monteiro et al., 2023)
DR8	Remote Monitoring	(Awouda et al., 2024)

The following analysis and categorization of SDGs related to CE and agriculture are derived from the United Nations report on Circular Economy (Castro de Hallgren et al., 2021). This comprehensive report outlines the principles and benefits of a CE, emphasizing the decoupling of economic growth from resource use, and the minimization of waste, emissions, and energy leakages through practices such as design, maintenance, repair, reuse, and recycling. The report highlights the importance of managing resource stocks and flows to preserve and restore environmental and natural capital, thereby contributing to sustainable development.

In line with this framework, Table 2 presents specific SDG targets pertinent to CE and agriculture, which are critical for achieving sustainable and resilient agricultural systems. These targets encompass a range of objectives aimed at enhancing agricultural productivity, ensuring food security, promoting sustainable resource management, and improving environmental quality. By aligning the benefits of DTs with these SDG targets, the table provides a comprehensive overview of how CE principles can be integrated into agricultural practices to promote sustainability and resilience.

Table 2: SDGs related to CE and Agriculture (Castro de Hallgren et al., 2021)

CN#	SDGs	Targets
CN1	SDG2 Target 2.3	Double the agricultural productivity and incomes of small-scale food producers
CN2	SDG2 Target 2.1	End hunger and ensure access by all people to safe, nutritious and sufficient food
CN3	SDG2 Target 2.4	Ensure sustainable food production systems, resilient agricultural practices, strengthen climate adaptation and improve land quality
CN4	SDG2 Target 2.b	Correct and prevent trade restrictions and distortions in world agricultural markets
CN5	SDG3 Target 3.9	Reduce air, soil, and water pollution
CN6	SDG6 Target 6.4	Water use efficiency
CN7	SDG8 Target 8.4	Global resource efficiency in consumption/production and decoupling economic growth from environmental degradation
CN8	SDG9 Target 9.4	Increase resource-use efficiency and resilient industrial processes
CN9	SDG11 Target 11.6	Improve cities' air quality and waste management
CN10	SDG12 Target 12.2	Achieve sustainable management and efficient use of natural resources
CN11	SDG12 Target 12.c	Rationalize inefficient fossil-fuel subsidies that encourage wasteful consumption
CN12	SDG13 Target 13.1	Strengthen resilience to climate hazards and natural disasters
CN13	SDG15 Target 15.1	Ensure conservation, restoration, and sustainable use of freshwater

Proposed Methodology

This paper proposes a robust methodology grounded in the HoQ approach of QFD, selected for its proven ability to design products and services that meet specific requirements while effectively incorporating customer feedback to ensure high quality through the relation matrix (Akao, 1990). The traditional HoQ methodology, though effective, has limitations in defining relationships beyond three levels, which can pose challenges in complex scenarios requiring nuanced relationship mapping. To address these limitations, this study employs fuzzy extensions of HoQ, which enhance the method's capability to handle multiple levels of relationship definitions. However, fuzzy approaches often encounter difficulties in managing ambiguous information and accurately capturing human cognitive processes, which are critical for a holistic understanding of customer needs and design requirements.

To overcome these challenges, this study introduces the 2-Tuple Linguistic (2TL) model, a sophisticated framework designed to represent linguistic information more comprehensively. The 2TL model enables a more accurate representation of human perception and preferences by providing a mechanism to address ambiguity and vagueness, which are inherent in human decision-making processes. This model enhances the quality and reliability of the design process by facilitating a nuanced understanding of the complex relationships between CNs and DRs. The 2TL model's strength lies in its ability to offer a relaxed assessment environment that aligns more closely with human cognitive processes, making it particularly effective for linguistic computations throughout all stages of the assessment process (Martínez, Rodriguez and Herrera, 2015).

The proposed methodology incorporates the 2TL model within the QFD framework, ensuring that the evaluation of CNs and DRs is both rigorous and reflective of real-world complexities. This integration not only mitigates the shortcomings of traditional HoQ and fuzzy approaches but also leverages the advantages of the 2TL model in representing computations in linguistic form. By doing so, it provides a more intuitive and accurate method for assessing and prioritizing design elements based on customer feedback and expert judgments.

The methodology involves several key steps, beginning with the identification and collection of customer needs and corresponding design requirements. These elements are then mapped within the HoQ framework, enhanced by the 2TL model to capture the linguistic nuances and cognitive perceptions of stakeholders. The process includes iterative evaluations and adjustments to ensure that the final design solutions are optimized for quality and customer satisfaction.

Despite originating as a linguistic decision-making technique in the early 2000s, the 2TL approach has evolved to offer significant advantages for various applications, particularly in areas requiring detailed and context-sensitive evaluations. The following figure outlines the steps of the suggested methodology, illustrating the integration of the 2TL model within the QFD process. For a more detailed exploration of the 2TL-QFD methodology, readers are encouraged to refer to Büyüközkan and Uztürk (2023), which provides an extensive discussion on the application and benefits of this advanced approach. The following Figure 1 present the general flow of the suggested methodology.

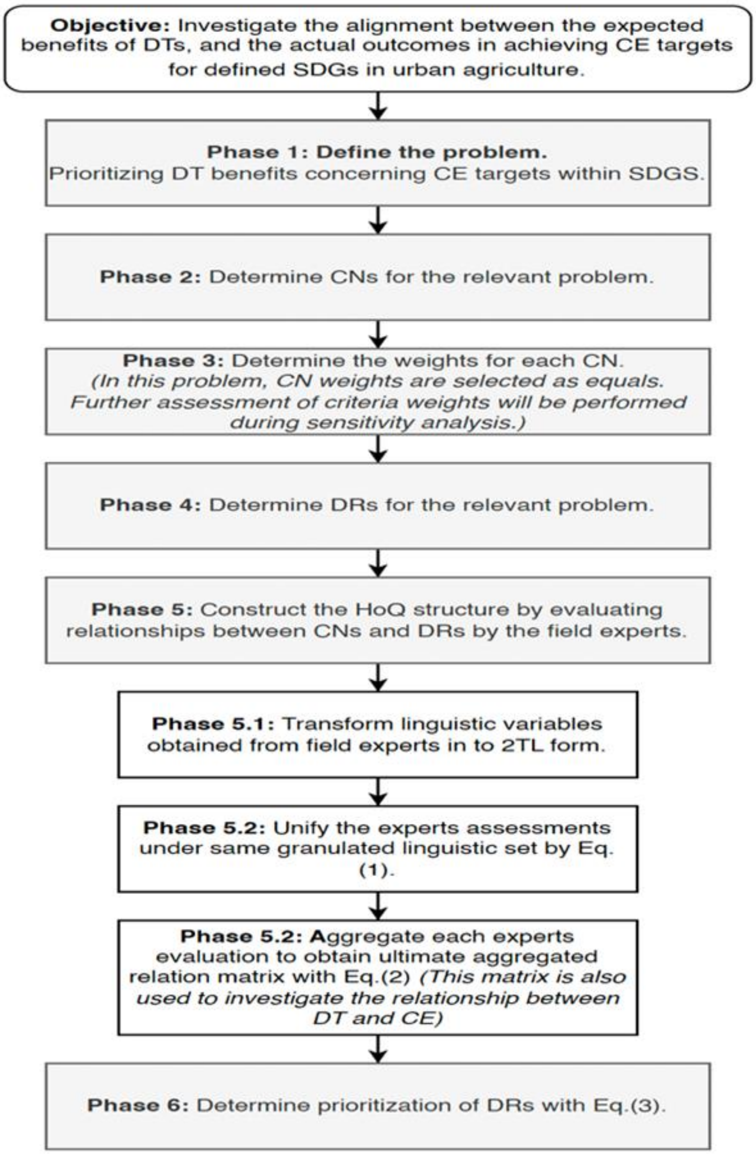


Figure 1: Proposed 2TL-HoQ

For the unification stage in Phase 5.2 the following equation will be used:

$$TF_{t'}^{t} = \left(S_i^{n(t)}, \alpha^{n(t)}\right) = \Delta\left(\frac{\Delta^{-1}\left(\left(S_i^{n(t)}, \alpha^{n(t)}\right) \times \left(n(t')-1\right)\right)}{n(t)-1}\right) \quad (1)$$

The transformation function to translate a linguistic term set with granularity *n(t)* to a linguistic term set having granularity *n(t')*.

The principal translation equation of 2TL is given as follows:

$$\Delta_s : \left[0, g\right] \rightarrow \overline{S}$$

$$\Delta_s(\beta) = (S_i, \alpha), with \begin{cases} i = round(\beta) \\ \alpha = \beta - i \end{cases}$$

$$S_i \in S \Rightarrow (S_i, 0)$$

Additionally, the *Weighted Average Operator (WAO)* will be utilized for aggregating expert evaluations due to its preference over other methods. This choice is driven by the recognition that experts possess varying weights based on their individual knowledge and experience in the subject matter (Martínez, Rodriguez and Herrera, 2015):

$$\vec{x} = \left(\frac{\sum_{j=1}^{n} \Delta^{-1}(r_j,\alpha_j) \times \Delta^{-1}(w_i,\alpha_i)}{\sum_{i=1}^{n} \Delta^{-1}(w_i,\alpha_i)}\right) = \Delta\left(\frac{\sum_{i=1}^{n} \beta_i \times w_i}{\sum_{i=0}^{n} w_i}\right) \qquad (2)$$

where, $(r_i, \alpha_i)$is the relative importance given for each CNs by each expert; (w_i, α_i)stands for the weights of experts and n represents the number of experts and β_i is the β values for *ith* CN's importance.

The importance of a DR will be calculated with the following relation (Li, 2012):

$$(v_i, \alpha_i) = 1/m \sum_{i=1}^{m} \Delta^{-1}\left(r_j, \alpha_j\right) \times \Delta^{-1}(s_{ij}, \alpha_{ij}) \qquad (3)$$

where, m stands for the number of CNs, $\left(v_j, \alpha_j\right)$is the importance of DRs as a result, $(r_i, \alpha_i)$is the weights of each CN and $\left(s_{ij}, \alpha_{ij}\right)$represents the values in the relationship matrix for *ith* CN and *jth* DR.

Case Study

In this case study, we engaged five experts with diverse backgrounds related to sustainability, food supply chain, IVF, and agriculture. Our expert group comprised three academicians specializing in supply chain management, sustainability, and agriculture, while the remaining two experts were modern urban farmers actively involved in IVF practices in Istanbul. Given the varying levels of expertise in IVF among the experts, different granulated linguistic sets were provided to ensure more accurate evaluations. The proposed linguistic sets are given as follows:

***S^5*:** *Very Low Related (VLR)-Low Related (LR)- Medium Related (MR)- High Related (HR)-Extremely High Related (EHR).*

S^9: *Absolutely Low Related (ALR)-Very Low Related (VLR)-Low Related (LR)- Medium Low Related (MLR)- Medium Related (MR)-Medium High Related (AHR)-High Related (HR)- Very High Related (VHR)-Extremely High Related (EHR).*

The academicians were asked to assess relationships using a linguistic set containing five variables, while the urban farmers evaluated relationships using a linguistic set containing nine variables.

To initiate the case study, an online meeting was organized with all field experts to introduce the problem statement and the proposed HoQ methodology. Together, we reviewed the United Nations report and identified relevant targets from Table 2 from the report (Castro de Hallgren et al., 2021) to establish CN for the defined problem. During this session, the linguistic sets were explained to each expert to ensure a clear understanding. Plus, experts were asked to validate the compiled DR list. Notably, based on feedback from the first and second experts, Supply Chain Efficiency (DR9) was added to the DR list to refine the evaluation process further.

Subsequently, within one week following the online meeting, Excel sheets containing the HoQ relation matrix were distributed to each expert via email. Experts were instructed to evaluate relationships using predefined linguistic terms provided as drop-down lists in the Excel sheets. Upon receiving evaluations from all five experts, the subsequent stages outlined in Figure 1 were strictly followed. These steps culminated in the development of an aggregated relationship matrix, synthesizing the inputs from all experts to gain comprehensive insights into the relationships. Weighting of the experts was crucial for the aggregation process using the WAO. To determine the weights, the granularity of the linguistic sets provided to each expert was considered. The assigned weights for experts ranged from 0.15 to 0.275, reflecting their expertise and granularity of linguistic sets. Specifically, experts 1 to 3 were assigned weights of 0.15 each, while experts 4 and 5, with more granulated linguistic sets, were assigned weights of 0.275 each. The ultimate aggregated relationship matrix of HoQ is provided with obtained linguistic DR weights (Table 3).

Table 3: Ultimate aggregated HoQ relation matrix and final prioritization of DRs.

CNS/DRS	DR1	DR2	DR3	DR4	DR5	DR6	DR7	DR8	DR9
CN1	(ALR,0)		(VHR, -0.35)	(EHR,0)	(MHR, -0.35)	(HR,0)	(EHR,0)	(MHR,0.35)	
CN2	(VHR, -0.35)	(MR,0)	(MR,0)	(MR,0)	(MLR, -0.35)	(MLR, -0.35)	(MHR,0.35)	(MR,0)	(HR,0)
CN3	(EHR,0)	(EHR,0)	(HR, -0.06)	(HR,0)	(MR,0)	(MLR,0.29)	(VHR, -0.29)	(MR,0)	(MHR,0.35)
CN4					(HR,0)		(HR,0)		(VHR,0.35)
CN5	(VLR,0.41)	(HR,0)	(HR, -0.06)	(EHR,0)	(VHR,0.35)	(VHR,0.35)	(VHR,0.35)	(VHR, -0.29)	(VHR,0.35)
CN6	(MR,0)	(LR,0)	(EHR,0)	(EHR,0)	(HR,0)	(VHR,0.35)	(EHR,0)	(VHR, -0.29)	
CN7	(VLR, -0.29)	(LR,0)	(VHR, -0.35)	(HR,0)	(MHR,0.35)	(HR,0)	(MR,0)	(MLR,0.29)	(MHR,0.35)
CN8	(VHR,0.35)	(HR,0)	(VHR,0.29)	(EHR,0)	(HR,0)	(HR,0)	(MHR,0.29)	(MHR, -0.35)	(HR,0)
CN9			(VHR,0.29)	(EHR,0)	(VHR,0.35)	(MHR,0.29)	(LR,0)	(LR,0)	(HR,0)
CN10	(MHR,0.35)		(VHR, -0.29)	(VHR,0.35)	(VHR,0.29)	(HR,0)	(MHR,0.35)	(MHR, -0.35)	(MHR,0.35)
CN11	(MR,0)		(VHR, -0.29)	(VHR,0.35)	(VHR,0.35)	(MHR,0.29)	(MLR,0.35)	(MLR, -0.35)	(VHR,0.35)
CN12	(EHR,0)	(EHR,0)	(VHR, -0.35)	(HR,0)	(HR,0)	(MHR,0.35)	(MLR,0.35)	(MLR,0.35)	(MHR, -0.35)
CN13	(MLR, -0.35)		(EHR,0)	(EHR,0)	(MR,0)	(MR,0)		(HR,0)	
$\sum \beta_j$	**48.12**	**36.00**	**79.82**	**84.71**	**74.00**	**59.18**	**64.77**	**53.35**	**60.77**
$\sum \beta_j /m$	(MR, -0.30)	(MLR, -0.23)	(HR,0.14)	(VHR, -0.48)	(HR, -0.31)	(MHR, -0.45)	(MHR, -0.02)	(MR,0.10)	(MHR, -0.23)
Ranking	8	9	2	1	3	6	4	7	5

Results of the Case Study

The ultimate aggregated relation matrix (Table 3) reveals a strong relationship between the benefits of DTs and the SDGs targets related to the CE, as indicated by comprehensive input from field experts. Nearly every cell in the relation matrix is filled by experts, underscoring the alignment between each DT benefit and at least one CE-related SDG target pertinent to IVF. Specifically, DRs 4 and 3 exhibit the highest relations with CE-related SDG targets, affirming the significance of DT in optimizing and automating agricultural practices for CE objectives.

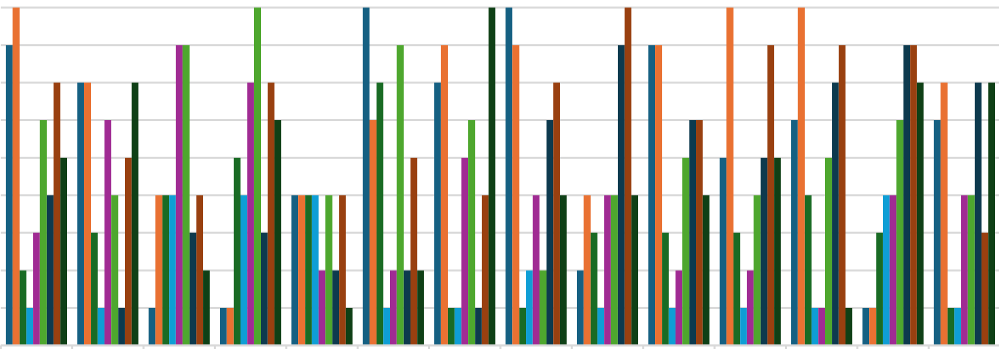
Upon closer examination of the detailed relationship between DRs 3, 4 and CNs, DR3 demonstrates a pronounced association with CN6 (Water use efficiency) and CN7 (Global resource efficiency in consumption and production), which received the highest assessments from experts. This observation validates the crucial role of DT in enhancing resource efficiency in agriculture, particularly in water management (Purcell and Neubauer, 2023). Furthermore, DR4 exhibits strong relationships with multiple CNs (CN1, CN5, CN6, CN8, CN9, and CN13), establishing it as a primary benefit to emphasize for efficient CE approaches in IVF. Consequently, the findings validate the pivotal role of DTs in enhancing CE for IVF, contributing to increased productivity, pollution reduction, efficient waste management, and conservation of natural resources (Preut, Kopka and Clausen, 2021).

The analysis highlights the integral role of DTs in promoting sustainability in IVF by optimizing resource use and automating processes. The strong relationships between DT benefits and SDG targets demonstrate the wide-ranging impact of DTs on various aspects of sustainable agriculture. By focusing on key design requirements such as resource use efficiency (DR3) and optimization (DR4), DTs significantly contribute to achieving CE objectives, ensuring sustainable management of resources, and enhancing productivity. These findings underscore the importance of integrating DT technology into agricultural practices to promote a resilient and sustainable agricultural ecosystem, thereby making a substantial contribution to the literature and offering practical guidance for stakeholders in the sector.

Discussions on the Case Study

Conducting a sensitivity analysis, as illustrated in Figure 2, is imperative for exploring the rankings of DRs under varying CN weights. This approach is essential because the proposed methodology initially omits CN weights, treating them as equal. However, it is crucial to recognize that CN weights may vary across organizations or countries when devising strategies for CE and SDGs. Therefore, adjusting CN weights can lead to tailored strategies for the utilization of DTs.

The sensitivity analysis, as depicted in Figure 2, shows that the importance assigned to each DR varies with changing CN weights. This variability underscores the adaptability of the proposed model, which can assist practitioners in planning how and for what purposes to integrate DTs within the IVF system. For instance, in Case 1, CN1 is given the highest importance, whereas in Case 2, CN2 takes precedence. This indicates that the model can accommodate different strategic priorities based on specific contextual needs. Figure 2 gives the sensitivity analysis results.



	Case Study	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6	Case 7	Case 8	Case 9	Case 10	Case 11	Case 12	Case 13
DR1	8	7	1	1	4	9	7	9	2	8	5	6	1	6
DR2	9	7	4	1	4	6	8	8	4	8	9	9	1	7
DR3	2	3	4	5	4	7	1	1	3	3	3	4	3	1
DR4	1	1	4	4	4	1	1	2	1	1	1	1	4	1
DR5	3	6	8	7	2	2	5	4	4	2	2	1	4	4
DR6	6	4	8	9	4	8	6	2	4	5	4	5	6	4
DR7	4	1	3	3	2	2	1	6	8	6	5	7	8	7
DR8	7	5	4	7	4	5	4	7	9	6	8	8	8	3
DR9	5	7	2	6	1	2	9	4	4	4	5	1	7	7

Figure 2: Sensitivity analysis.

Within the HoQ methodology, the ranking of DRs emphasizes the significance of Optimization, Automation, and Management for IVF. This aligns with the findings of Kabir et al. (2023), which suggest that DT systems designed to optimize processes, automate operations, and manage resources effectively are instrumental in enhancing CE within IVF. Based on the rankings in the sensitivity analysis table, DR4 (Optimization) stands out as the most frequently prioritized DR, appearing as the top-ranked priority in six cases. This insight suggests that the optimization benefits of DTs are crucial for achieving CE objectives in IVF.

Moreover, to fully realize the benefits of DTs, it is essential for IVF systems to explore advanced data collection systems, such as the Internet of Things (IoT) and advanced sensor systems. These technologies are pivotal in establishing the cyber replica of the IVF system, as highlighted by Martindale and Lucas (2021). By integrating IoT and advanced sensors, IVF systems can enhance their data accuracy and real-time monitoring capabilities, which are crucial for the effective implementation of DTs. This integration not only supports the optimization and automation of processes but also improves the overall management and sustainability of the IVF system.

The prioritization of optimization (DR4) in the majority of cases highlights its crucial role in enhancing the CE within IVF. Optimization boosts efficiency and productivity by ensuring efficient use of resources such as water, energy, and nutrients, thereby minimizing waste and operational costs. Integrating optimization technologies with Digital Twins (DTs) should be a strategic focus to achieve CE objectives (Nasirahmadi and Hensel, 2022). While optimization is key, automation and management are also essential. A holistic integration of these benefits will create resilient and adaptable IVF systems capable of meeting diverse sustainability goals. The sensitivity analysis underscores that by prioritizing optimization and integrating it with automation and management, practitioners can significantly enhance the efficiency, sustainability, and resilience of IVF practices, contributing to broader CE objectives in agriculture.

Concluding Remarks

In conclusion, this study has utilized the HoQ of QFD methodology, combined with the 2TL model, to explore the intricate relationship between DTs and the CE within the context of IVF. The integration of the HoQ's relation matrix with the 2TL model has created a flexible analytical environment, facilitating a comprehensive understanding of the interactions between various factors and their resulting outcomes. Through this robust approach, we have illustrated the critical role of DTs in optimizing and automating IVF systems to enhance CE outcomes.

It is important to recognize the limitations of this study, particularly the scope of expert evaluations being confined to Turkish experts. Future research endeavors should aim to broaden the spectrum of expert evaluations to include a more diverse and global perspective, thereby improving the generalizability and applicability of the findings. Additionally, our analysis has drawn upon the benefits of DTs as reported in the literature, complemented by evaluations from both the authors and field experts. This synthesis has provided valuable insights into the multifaceted benefits of DTs in the context of IVF and CE, serving as a foundation for future research and practical applications.

Looking ahead, there are several promising avenues for further exploration in the application of DTs in IVF for CE. One significant area involves the selection of DT providers, where factors such as data integration capabilities, real-time monitoring features, and decision support functionalities should be meticulously considered to ensure effective optimization and automation. Furthermore, future research should focus on identifying the critical attributes that a DT must possess to facilitate efficient optimization and automation within IVF systems. By addressing these considerations, we can deepen our understanding of how DTs can be leveraged to drive sustainability and efficiency in agricultural practices, thus contributing to the broader objectives of achieving a CE in the agro-food industry.

In summary, the findings of this study underscore the substantial potential of DTs to transform IVF systems through enhanced optimization, automation, and management. The methodologies and insights presented herein provide a robust framework for future research and practical implementation, aiming to harness the full potential of DT technology in promoting sustainable agricultural practices and achieving CE goals.

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Ensuring Sustainable Food Consumption in India: A Study on the Buying Behaviour

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Extended Abstract

We have conducted a study on the moderating role of socio-demographic influences in the purchase patterns of organic food, with a particular focus on the specific brands. Our research has elucidated the nuanced factors that drive organic food purchases, highlighting the relative importance of health benefits, environmental impact, and ethical considerations. Additionally, we have identified both opportunities and challenges within the organic sector in India

As the world is growing with the looming large share of 9.6 billion population by 2050[1], the notion of sustainability remains pivotal in the future food systems. Making the food production and consumption sustainable can help overcome this gigantic challenge. Organic food system has immense potential to offer an effective approach towards sustainability (Gammage et al., 2023). Despite mitigating the greenhouse effect and global warming through sequestering carbon in the soil (Clark, 2020), organic food systems also ensure higher crop yield, reduced water wastage and soil erosion (Baker et al., 2015), and economic resilience (Schader et al., 2012). Organic farming practices are widespread across 187 countries, contributing to 1% of the world's agricultural area, making it one of the fastest growing sectors (Gammage et al, 2023). Interestingly, in terms of the number of producers, India had 1.4 million of organic food producers in 2019, making it the world's largest producer of organic food (Willer et al., 2021). Besides, according to the Organic India Market Report (2022), the Indian organic food market has experienced a 25 % year-on-year growth with a potential to reach 64 billion by 2025.

Despite the tremendous potential of the India's organic food sector there are both supply side and demand side constraint surrounding the Indian Organic food market. While infrastructural constraint, higher input costs, lack of financial support are the major supply side challenges, higher price, lack of awareness, less available and unattractive labels are the prominent demand side constraints of organic food consumption in India. These constraints have translated into lower consumer demand for the organic food as compared to the other developed economies (Khushwa et al., 2019). Furthermore, the extant literature on the organic food consumption is limited in terms of its scope and application as the studies analyse only the direct impact of factors on the buying behaviour. Our study aims to extend the existing framework of the consumer buying behaviour towards organic foods by incorporating moderating effects of the socio-demographic factors and applying the framework for the Indian markets.

[1] https://www.un.org/en/global-issues/population

Using the survey method of data collection, we obtained the data for the customers of specific and large brands. For data analysis structural equation model (SEM) method was employed. Partial least square (PLS) is a parameter estimation method of SEM. We use the PLS-SEM method where measurement model is analysed to test the validity and reliability and then SEM is used to for testing the hypothesis. Our results point that the buying behaviour and purchase intentions of organic food in India are influenced by a variety of factors including health consciousness, environmental awareness, and socio-economic status. Indian consumers are increasingly becoming aware of the health benefits associated with organic food, which is free from synthetic pesticides and chemicals. This health consciousness drives a significant portion of the market, especially among urban and educated consumers. Environmental concerns also play a critical role, as consumers who are aware of the negative impacts of conventional farming on soil and water resources tend to prefer organic alternatives. Socio-economic factors, such as income levels and access to organic food markets, further shape buying behaviour. Higher income groups are more likely to afford the premium prices of organic products, while availability and accessibility of organic food in local markets also determine purchase intentions. Additionally, cultural values and traditional preferences for natural and unprocessed foods bolster the demand for organic products in India. Overall, the interplay of health, environmental, and socio-economic factors create a growing and dynamic market for organic food in the country. An understanding of the demand pattern of the Indian consumers for the organic foods is essential for the producers and the policy makers to comprehend consumer’s view and remove the demand side constraint.

Keywords

Sustainable Food Consumption, SEM,Purchase intention, Buying Behaviour, Organic Food

Presenter Profile

Anandita Ghosh is an Assistant Professor of Economics. She has a relatively newer yet impactful research track record with quality publications & conferences to her credit. Her research areas are Climate Economics and Energy Economics.

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