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The Bio Steel Cycle Meets Indoor Farming - CCUS with the SusCiP Principle in Agriculture

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Abstract

The World climate is changing, with a great impact on global food production systems. Extreme weather events, floods, wildfires and droughts are phenomena of disrupted previously stable natural weather patterns, which are vital for crop production and animal husbandry alike. Most of the World's food is produced in temperate climatic zones rich in arable land and those are affected by the increasing unpredictability of previously naturally occurring seasons and weather conditions. This work aims to provide a possible sustainable solution to food production challenges under the pressures of climate change. Changing food production methods by moving to indoor agriculture poses great challenges and immense opportunities at the same time. Technical solutions are currently researched and explored by innovators, governments and industry leaders alike. The previously developed Bio Steel Cycle can be seen as the nucleus for other industries, including food production, and could be the starting point for a new standard in all production systems: The SusCip principle.

Keywords
Sustainable indoor farming; SusCiP principle; farm diversification

1. Introduction

The World climate is changing, and the occurrence of extreme weather phenomena is increasing at an alarming rate [1, 2]. The jet stream, which has provided the mid-European geographical zone with a temperate climate is changing [3]. El Nino has been largely replaced by la Nina, with a great impact on food production systems [4-6]. Extreme weather events, floods, wildfires and droughts are phenomena of disrupted - previously stable - natural weather patterns, which are vital for crop production and animal husbandry alike [7-10]. Most of the World's food is produced in temperate climatic zones, north and south of the equator, stopping short of the Arctic/Antarctic latitudes [11-14]. Although this zone was once rich in arable land, the overuse of soil disrupting farming techniques and application of fertilizers, pesticides, fungicides and desiccating agents have depleted the soils' rich microbiome and the resulting crops have dramatically dropped in nutrient values [15-19]. These climatic zones suitable for arable use are decreasing in size due to the increasing unpredictability of previously naturally occurring seasons and weather conditions, and the agricultural industry is struggling to meet the demand for the quantities of nutritionally valuable and sufficiently available food to feed an increasing World population [20-26].

This work aims to provide a possible sustainable solution to food production challenges under the pressures of climate change [10, 14, 18]. Changing food production methods by moving to indoor agriculture and using other innovative systems [27-29], such as aquatic and floating food farming. As an interesting working example: in China, farmers are using integrated systems, where rice and fish are grown together in a perfect symbiosis: the fish are living among the water in which the rice is grown, and they are fertilising plants with their excretions as they go about their daily lives and feed on the pests affecting the rice crops - thus no fertilizer or pesticides are needed [30, 31]. Other systems offer immense opportunities, which have been successfully used for food production thousands of years ago, when our ancestors, such as the Inkas, cultivated swamps with their floating farms and made water-logged land, otherwise unsuitable for traditional farming, successful food production sites [32-35]. Obviously, making these innovative and old ideas work in the 21st century are posing great challenges - but they also offer immense opportunities at the same time [32].

Technical solutions for indoor farming and other advanced innovative and ancient food production systems are currently researched and explored by innovators, governments and industry leaders alike [36-38]. For arable farmers in particular, the model and strategy of the Bio Steel Cycle [39] can be seen as the nucleus to provide a food production process blueprint, which can provide the benefit of increased asset efficiency and opportunities in farm diversification, utilising the existing building infrastructure and adding CCUS (carbon capture utilisation and storage) technologies.

The Bio Steel Cycle model and strategy [1] consists of the following main components, explained also in the '7 Steps' in the text:

- <u>Carbon capture</u>
- <u>Carbon utilisation</u>
- <u>Integration of renewable energy</u>
- <u>Replacing fossil fuels with biomass and renewable energy</u>

- Utilising CEPS (carbon enrichment for plant stimulation) and DAC (direct air capture)
- Process improvements and energy loss reduction (exergy analysis)
- Installation of anaerobic digesters

The Bio Steel Cycle model and strategy [39] provides elements for a multi-disciplined approach of production processes in other industries, including food production, and is the foundation for a new standard in production: The SusCiP principle. The applied SusCiP principle offers increased asset efficiency of up to and innovative farm diversification potential whilst capturing and utilising carbon at the same time.

2. Materials and Methods

Throughout this project, global data sets in connection with renewable energy technology implementation in different settings were utilised [40-49]. Information on factual CO_2 emissions in agriculture in a range of geographical settings have been considered [50-57]. The gathered data was analysed and used for modelling using MS Excel and process simulations software, and simultaneously analysed by applying standard mathematical principles, and standard statistical methods such as the t-test were carried out to have comparable results to the reports from process simulations. Although there are currently several projects in progress concerned with filtering CO_2 emissions from any production process, a solution needs yet to be found which could be a solution to 100% filtering of CO_2 emissions.

There are two significant hurdles to the implementation of sustainable agriculture and indoor food production techniques: (1) lack of willingness across the agricultural sector to incorporate the required changes in their financial and production planning whilst managing the installation of suitable technology and (2) lack of viable financing provision of all efforts provided by the respective governments. The first hurdle relies on the agricultural sector leaders and associations to act and drive the decarbonisation of the agricultural sector to avert climate disaster, as politicians worldwide seem to lack the willingness to implement and enforce adequate policies-despite the extreme weather events affecting every one of us. The second hurdle has been partly addressed by governments across the globe and the UK government with grants, loans, and subsidies.

One of the author's preceding publications 'The 7 Steps to Net Zero CO_2 Emissions Steel Production' [39] strategy can be seen as a guidance paper for the decarbonisation of all industrial sectors, including agriculture - in tandem with this publication and 'Greater Energy Independence with Sustainable Steel Production' [58] as a guideline for achieving higher energy independence, simultaneously. The systems implementation, as described [58], will likely achieve a higher degree of energy independence, in the short term. It could be achieved in seven easy-to-follow steps, even if only some sections of the following are being applied:

Step 1: Switching to a 100% green energy provider

Step 2: Installing (subsidised) renewable energy technologies

Step 3: Replacing coal and coke with biomass (biochar)

Step 4: Installation of carbon capture technology

Step 5: Utilisation of CO_2 in food and building projects

Step 6: Further process improvement in agriculture

Step 7: Implementation of anaerobic digesters

The installation of anaerobic digesters wherever possible would have the added benefit of providing an opportunity to help farmers to create energy from waste management and create carbon neutral fertiliser at the same time. The pellets pressed from the anaerobic digestate, and effluents can be added as natural fertiliser, and no harmful and oil-based chemicals have to be applied to the soil to maximise yield. Conventional energy use and renewable energy component implementation points have been incorporated to highlight the simplicity of achieving a higher degree of energy independence, whilst simultaneously decarbonising the steelmaking process.

2.1 Results

2.1.1 Climate Change Impact on Food Production

Floods, droughts and fires and other extreme weather events are destroying crops and are reducing the arable land to produce food on [2-4]. Changing seasons as the result of El Niño being replaced by La Niña are making outdoor food production systems a perilous and partially non-viable enterprise for farmers worldwide [5-7]. Food and water poverty are some of the driving factors for emigration, worldwide, and the aim or eliminating poverty and achieving zero hunger across the globe requires a new approach to food security and food production, as the systems of old are not sufficiently efficient to meet current needs and are threatened by changing and extreme weather phenomena [2-4]. Flooding and other effects of extreme weather events are disrupting the supply of clean water and pose an increased risk to health and sanitation [8-10]. It is therefore imperative to change the food production systems in a way which support meeting the needs of current and future generations of the world population but also ensure water security [11-15]. Introducing the Bio Steel Cycle mechanisms and the SusCiP principle can support development of more secure food production and clean water supply. The integration of affordable and renewable, clean energy is a vital component of these models and could support food production in developed and developing countries.

2.1.2 Indoor Food Production Technical Solutions - The Industry Leaders

For farmers, indoor farming provides opportunities for increased asset efficiency; as an example, barns previously only used for storage could be easily converted into an indoor food production facility, using structurally sound agricultural buildings and taking advantage of the new planning laws [16-18]. Additional income streams can be generated by taking up the opportunities of indoor farming for the agricultural industry and, simultaneously, for farmers as being the drivers of CCUS and a sideline: soil farming [19, 20]. Considering that the agricultural sector is responsible for 30% of global CO_2 emissions, and in the UK alone, the agricultural sector contributes hugely to emissions of nitrous oxide, methane and carbon dioxide: accounting for 71% of total nitrous oxide emissions and 49% of all methane emissions in 2021 NOW [49]. Technical solutions are currently researched and explored by innovators, governments and industry leaders alike. For arable farmers in particular, the model and strategy of the Bio Steel Cycle can be seen as the nucleus to provide a food production process blueprint, which can provide the benefit of increased asset efficiency and opportunities in farm diversification. Furthermore, CAPEX heavy asset investment could become a thing of the past, as heavy machinery for tilling, mulching, turning, harvesting and transport are obsolete. The following Table 1 aims to provide an overview of some of the industry leaders providing indoor farming technology and solutions:

Table 1 Indoor farming technology companies.

Company Name	***Country***	***Links and information***	***Author***
Futurae Farms	U.S.	Futurae Farms - The Future of Food Futurae Farms is a next-generation farming company, focused on vertical farming solutions to reduce supply chain issues and mitigate the effects of climate change	[21]
CubicFarms	Canada	ESG Commitment - CubicFarm Systems Corp Provider of indoor growing systems with the focus on using fewer natural resources and eliminating the need for pesticides, herbicides, or fertiliser	[22]
Aero Farms	United Arab Emirates	AeroFarms the Vertical Farming, Elevated Flavor Company as a Certified B Corporation, they use the latest technologies in indoor vertical farming, utilising artificial intelligence and natural plant biology to improve fresh produce production and local/global distribution	[23]
InFarm	Germany	Infarm Innovative high-capacity, automated, modular growing centre system. Representing a local farm and distribution center at one site, with a capacity to generate the crop-equivalent of up to 10,000 m^2 of farmland, and up to 400-times higher efficient food production than soil-based agricultural production	[24]
Spread	Japan	Sustainability Spread Stable food supply through automated production, efficient operations supported by IoT (intelligent operating technology), and a widely connected distribution network	[25]
Farm66	Hong Kong	Home - Farm66 | Green, Fresh, Safe and Healthy | First Indoor Aquaponics Farming in Hong Kong Farm66 have develop an indoor farming system, growing quality vegetables locally and efficiently, which uses patented in-house innovations: • “Multi-layer Vertical Planting (MVP) structure” • “Soilless Hydroponics Farming (SHF) techniques” • “Indoor Aquaponics Farming Eco-system (IAFE)”, “Energy-efficient LED Wavelength Farming” • “Cloud-based Farming Parameters (CFP) monitoring”	[26]
iFarm	Finland	Vertical Farming Technology iFarm have developed the following indoor farming systems, which have a broad application range: • iFarm Leafy Greens	[27]

- iFarm StackGrow
- iFarm Microgreens
- iFarm Growtune software
- iFarm Berries
- iFarm Veggies
- iFarm Tree Grow
- iFarm Container

The Bio Steel Cycle model and strategy [1, 28] provides elements for a multi-disciplined approach of production processes in other industries, including food production, and is the foundation for a new standard in production: The SusCiP principle. The applied SusCiP principle offers increased asset efficiency and innovative farm diversification potential whilst capturing and utilising carbon at the same time.

2.1.3 Following Sustainable Circular Production Practice - The SusCip Principle

The SusCiP principle (Figure 1) was created with the Bio Steel Cycle as its foundation and guiding principles. The components of sustainability, circularity, ecological and socio-economic improvement, as well as sustainable production processes designed to only emit water and oxygen are the key elements of this framework.

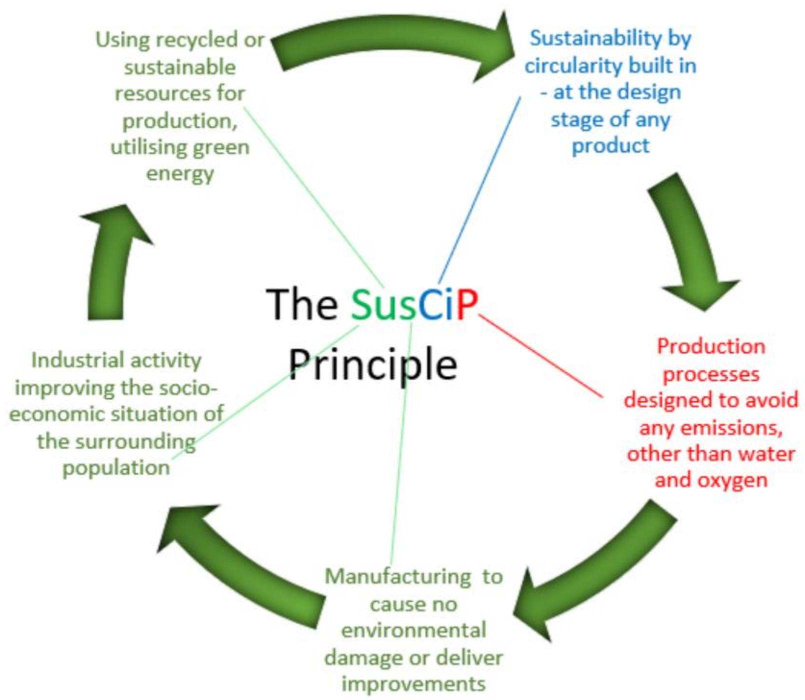

Figure 1 Sustainable circular production practice - The SusCip principle.

Designing all manufacturing and production processes with sustainability and circularity in mind can support achieving the net zero nationally determined contributions (NDC) [29] to achieving a net zero carbon emissions society, as well as improving the economic situation for arable farmers - particularly hill farmers in the UK - and helping to support the safeguarding and regeneration of the natural environment.

2.1.4 The BiSC as Nucleus for Other Industries: The Bio Steel Cycle Meets Indoor Farming

Ideally, any future building project in agricultural businesses is based on a (green) steel frame, and using integrated solar panels as glass substitute in greenhouses or combined agricultural production facilities. Integration of renewable energy components (displayed in Figure 2) is key, which were produced using green steel [30], generated with the Bio Steel Cycle System [1, 28] in mind. Other elements such as production process improvement, waste and resource recycling are offering multiple opportunities for carbon capture, utilisation and storage in (indoor) farming (Figure 2).

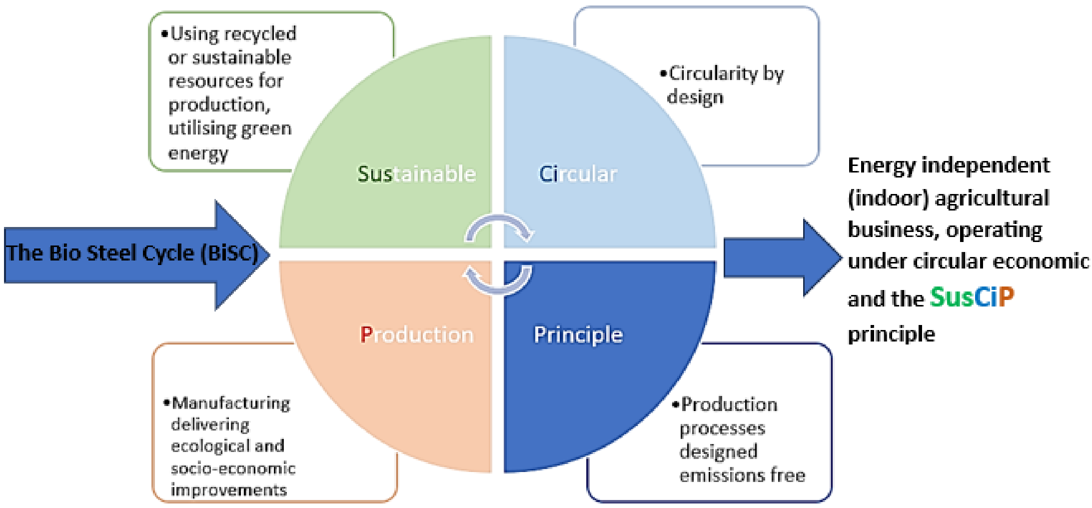

Figure 2 The Bio Steel Cycle and the applied SusCiP principle in agriculture.

With renewable energy technology implementation (solar, wind, anaerobic digesters), improvement of the socio-economic situation for arable farmers can be achieved in many ways, alongside increasing asset efficiency and generating their own organic fertiliser. Implementation of renewable energy technologies [31], produced using the Bio Steel Cycle model and strategy for green steel [1, 28], already reduces the amount of CO_2 emissions and the need for fossil fuel combustion to generate energy. Additionally, a substantial range of projects can be CAPEX neutral, meaning they don't have to be financed using traditional financial sector credit lines or loans, as there are funding opportunities available for almost every carbon reduction solution. More details can be found in the following Table 2:

Table 2 Incentives, grants and funding.

Scheme	Description	Author
England Woodland Creation Offer	Landowners, land managers and public bodies can apply to the England Woodland Creation Offer (EWCO) for support to create new woodland. Over £10,000 per hectare.	[59]
Greening Eden	The CBEN Partnership will complete the calculations using data provided by each company and site visits to provide practical and cost-effective advice on how to reduce emissions. A £400,000 grant fund has been established to help to capital investment projects delivering emission reductions.	[60]

Green Heat Network Fund	Commercialisation and construction of new low and zero carbon (LZC) heat networks (including the supply of cooling). Retrofitting and expansion of existing heat networks. Funding will support the uptake of low-carbon technologies like heat pumps, solar and geothermal energy as a central heating source. The GHNF is open to organisations in the public, private, and third sectors in England (no individuals, households, sole traders).	[61]
Green Gas Support Scheme	Funding support for biomethane injection to the national grid.	[62]
Clean Heat Grant	Upfront capital funding for households and businesses for the installation of sustainable heating technologies (heat pumps, biomass).	[63]
Smart Export Guarantee (SEG)	The SEG funds for the low-carbon electricity exporters, feeding back to the National Grid. Anyone with an installation of one of the following technology types is eligible to apply: Solar photovoltaic (solar PV), Wind, Micro combined heat and power (micro-CHP), Hydro, Anaerobic digestion (AD) support and grants for SMEs to help them to reduce carbon emissions.	[64]
SMEES	SMEES (SME Energy Efficiency Scheme): Guidance and funding for businesses looking to improve their energy efficiency.	[65]
Energy for Business	Support and grant funding for SMEs with projects to reduce carbon emissions or save energy.	[66]
HNIP	Heat Networks Investment Project (HNIP) government-backed funding.	[67]
Low Carbon Dorset	Free support to help businesses in Dorset reduce their carbon emissions, improve energy efficiency and aid the development of new low carbon products.	[68]
Business Energy Efficiency Programme	Energy reviews and grants to help businesses in the West Midlands manage and reduce energy costs.	[69]
Green Gas Support Scheme (GGSS)	Provides tariff support for biomethane produced via anaerobic digestion, provided this is subsequently injected into the gas grid.	[70]
Horizon Europe funding	Funding for research or innovation that's groundbreaking, improves European research standards or responds to challenges like climate change or food security.	[71]
Coventry and Warwickshire Green Business Progr.	Grants, free energy audits and low carbon product development support for businesses.	[72]
DE-Carbonise Project	Derby and Derbyshire.	[73]

The Bio Steel Cycle model and resulting strategy is based on the 7 steps to net zero carbon emissions steel production, which is an easy-to-follow framework. How this relates to agricultural practices will be detailed in the following:

Step 1: Switching to a 100% green energy provider:

This is universally the same across all industries and even residential and commercial settings. Literally by the stroke of a pen, or signing up online, individuals and businesses are able to exert their consumer power to turn away from fossil fuel derived energy and commit to a supplier which generates 100% green and sustainable energy.

Step 2: Installing (subsidised) renewable energy technologies:

Utilising existing buildings and infrastructure, agricultural enterprises are able to not only produce their own energy, making these businesses partially or entirely energy independent. Given the current energy price volatility and the prices per unit of electricity only increasing, this could pose a valuable and profitable route of making agricultural businesses more future-proof. But farmers and agricultural businesses are also able to develop farm diversification opportunities, with the installation of anaerobic digesters, solar photovoltaic (PV), caged or rotor-bladed wind turbines and hydro-power systems. After all, with the earth consisting of 71% water [32], hydro power (windmills close to rivers, brooks and natural or artificial lakes) has been the driving force behind the development of agricultural businesses, such as flour milling [33-37]. Anaerobic digesters utilise the organic matter: manure, produced on meat production facilities in vast quantities [38, 39] of estimated 20 million tonnes of dry and organic matter - every day. Besides solving the waste management problem for agricultural businesses, anaerobic digesters are producing biogas as their main product, and the digestate (residue from the microbial breakdown of organic matter) can be pressed as pellets and used as organic fertiliser, entirely without the use of external chemical components, energy-intense production processes or the addition of harmful substances or fossil fuels [40-42].

Step 3: Replacing coal and coke with biomass (biochar):

BECCS (meaning: bioenergy with carbon capture and storage), is a geo-engineering [43] technique which - besides being a direct and viable alternative for energy derived from fossil fuels, removes CO_2 from the atmosphere via direct air capture (DAC). DAC is the process by which plants absorb CO_2, the main building block for plant growth [44, 45]. BECCS is being proposed as one of the possible solutions [43, 46-48] to prevent carbon emissions to be exceeding the emissions levels of the 2015 'Paris Agreement' [49] on climate change with the aim of limiting the global temperature rise to less than 1.5 degrees Celsius of pre-industrial temperature levels. One of the so-called energy crops of growing biomass is Miscanthus [50], mainly Miscanthus x giganteus, which is a sterile hybrid which does not produce viable seeds. This is one of the reasons of its growing popularity, at it makes it less likely to spread unintentionally, and has therefore established itself as one of the most popular energy crops in the UK [51] and the EU (European Union) [52, 53].

Step 4: Installation of greenhouse gas and carbon capture technology:

One of the technologies available at technical readiness levels 6-9 (TRL) for carbon and methane capture and is the installation of filters. In recent years, a growing number of projects across the globe have been developing solutions for this issue, with a range of different approaches [54]. Reliable industrial-scale carbon filters and methane capture systems consisting of a range of processes and technologies are currently produced, in addition to carbon filters [55, 56].

Methane emitted from manure and agro-industrial waste management systems can be captured using anaerobic digestion (AD) technology, using a range of solutions: such as small-scale digesters, enclosed anaerobic lagoons, plug-flow-digesters, complete mix digesters, and advanced digesters [57].

Step 5: Utilisation of CO_2 in food and building projects:

Utilising plants' natural ability to absorb carbon, CO_2 and greenhouse emissions from agricultural businesses can be redirected into greenhouses for food production (CEPS: Carbon Enrichment for Plant Stimulation) [1, 58], without ever reaching the atmosphere. Studies have shown methane's (CH_4) involvement in plant growth and development, particularly in seed germination, promoting seedling growth, improved lateral rooting and adventitious rooting, and improved post-harvest freshness of produce. Methane also improves plants' resilience and response to abiotic stresses (osmotic stress, salt and heavy-metal stress [74-76].

Step 6: Further process improvement in agriculture:

No till farming, and using 'old' (meaning: not genetically or otherwise altered) plant varieties [77-80] is gaining momentum and the reduced time, cost, fertiliser/pesticide/fungicide-use and manpower investment, besides improved yields per hectare seem to be heralding a systemic change in agricultural practice [20]. More sustainable solutions to food production challenges under the pressures of climate change [10, 14, 18] need to be found, and reducing the stresses on arable land and the farmers involved by adopting a no-till practice seems to be a viable solution. A changing climate is forcing changes in traditional food production methods and moving some agricultural indoors using innovative systems [27-29], and using advanced methods such as hydroponics [81-84], aquatic, and floating food farming [30, 31] systems. Other systems offer immense opportunities, which our ancestors have been taking advantage of successfully thousands of years ago, when they cultivated swamps with their floating farms and made water-logged land, unsuitable for traditional tilling and sowing farming, successful food production sites [32-35]. Making these innovative and - at the same time - old ideas work in the 21st century are posing great challenges - but they also offer immense opportunities at the same time [32].

Step 7: Implementation of anaerobic digesters > biogas production and/or green hydrogen:

Anaerobic digesters in their various forms offer solutions to some of a variety of challenges farmers and agricultural business are confronted with: Waste management, Effluent management, Nitrate over-saturation of soil and water, and the cost of agricultural workers. By using integrated manure and effluent removal systems in animal production, and using this as feedstock for the anaerobic digesters, reduces the cost and time agricultural labourers have to spend cleaning up after their life stock. At the same time, these waste products are used for generating biogas, which in turn can be used to serve the businesses' energy needs. Additionally, it is possible to split hydrogen from the feedstock at different stages in the anaerobic processes, but there is yet a grant, subsidies or green loans to be provided by the finance sector and respective government to make the technology attractive for agricultural businesses. And there are other technologies which are more efficient for making hydrogen, such as electrolysis from seawater [85].

Table 2 provides an overview of financial incentives currently provided by the UK government, which support agricultural businesses on their journey to a more sustainable, less greenhouse gas intense way of producing the food we need.

Additionally, there is a range of methods available to optimise the indoor farming approach, as per the BiSc strategy step 6, detailed in Table 3:

Table 3 Step 6 - Case studies on optimisation options for indoor farming.

Optimisation approach	**Summary**	**Relevant studies**
Strategies for carbon emissions reduction, increased energy efficiency, and energy management in buildings	86) This study provides details of emerging sustainable technologies and strategies which have the potential to assist in achieving building decarbonisation. The main technologies reviewed in these studies include: • renewables integration	[86]

	• building retrofits • energy demand flexibility • data-driven modeling improved control • grid/buildings integrated control • uncertainty-based design • thermal energy storage • thermal energy sharing • heat pump technologies	
	87) This work demonstrates ways to achieve: • robust hybrid assessment tools for CCUS • modeling, simulation, and optimisation methodologies (based on artificial intelligence) (AI)	[87]
	88) This review examines: • the role of data science and artificial intelligence (AI) techniques • AI techniques in energy consumption analysis • identifying patterns and discovering efficiency opportunities	[88]
Energy-efficient solutions for low-carbon applications in agriculture	89) This work investigates the reduction of greenhouse gas emissions through the substitution of tractor diesel oil with biomass and provides insight into: • feedstock • the inter-esterification process • the storage period • ambient conditions • increased fuel use efficiency • reduced fuel consumption • power/load matching	[89]
	90) This book carried out an investigation in agricultural applications and provides reports on: • thermodynamics investigation • analyses of temperature/humidity controls • technologies for agricultural applications • optimisation of fruits and vegetable storage • poultry air-conditioning • livestock thermal comfort • wet market air-conditioning	[90]
	91) The methods used in this work include a systematic analysis of current technologies/applications in optimising greenhouse design and functionality. This comprehensive review examines advancements in: • improving the energy performance of agricultural greenhouses • highlighting innovations in thermal and energy efficiency	[91]

	• energy efficiency of heating and cooling systems	
Designing energy-efficient buildings in urban centres through machine learning to support sustainable food production efforts	92) This study utilised regression analysis with support vector machines (SVM) and k-nearest neighbours (KNN), and investigated the innovative integration of: • agricultural use nano-composite materials (Silver Nanoparticles (AgNPs)) • elevation of water treatment efficiency • assessment of the resulting environmental and energy-saving benefits	[92]
	78) This review took a holistic approach and provided a critical summary of the existing literature on the machine and deep learning methods (artificial intelligence - AI), successfully applied to developing solutions for the built environment	[93]

The need to move agricultural food production indoors and use innovative systems, as well as reviving old farming practices, has been recognised a long time ago and as per Table 1, innovative entrepreneurs have developed climate change resistant farming practices, which have the potential to ensure long-term food safety and security.

2.1.5 Greater Energy Independence in Indoor Farming

Moving farming activities indoors can prove to be a challenge, for which there are a range of technical solutions at hand (Table 1) and a wide range of studies have been conducted (Table 3) to support decarbonisation of buildings and agricultural structures, partially with the support of machine learning and artificial intelligence (AI). Plants need light, nutrients and water to grow [94]. But the nutrients do not necessarily have to be delivered via the root system by residing in soil: Vertical indoor farming in rows of pipes, where the plants inserted at the top are being supplied with the necessary water and nutrients via a network of pipes, circulating around the root system [95-97]. The UV light is provided with lamps, installed to provide the right brightness, wave-length and duration of light hours for optimum yield [98-100]. This requires energy, which can either be provided by installing solar PV and solar thermal panels, suitable capacity wind turbines and biogas from anaerobic digestion [31, 101]. In an ideal situation, this could lead to energy independence at nearly 99%.

These components would ideally be produced using the Bio Steel Cycle system [1, 28], where all resources are either reduced in their carbon footprint, have been recycled in their own right or utilised to generate new energy - which is then fed back into the manufacturing or production system. In all likelihood, the mix of renewables installed, and the electricity produced will by far exceed the requirements of the indoor farming installation and can therefore be used to supplement other farming operations onsite, or even the - possibly nearby located - private quarters of the owner. This creates a situation of almost complete energy independence for agricultural businesses and decreases their dependency on the national grid for their energy supply. To emphasise this point in the figures, this creates an immediate drastic reduction in CO_2 emissions of 88%, as solely renewable energy technology is used to generate electricity, and not fossil fuels. Offheat from (steel) production is harvested and transferred to indoor food production sites (greenhouses).

Figure 3 displays the cyclical indoor farming system. If the technology is implemented this way, food producers will not be exposed to price fluctuations anymore, which have driven a great proportion of farmers and businesses in the UK and elsewhere to close their operations, as the energy cost pressure made these no longer viable. Anaerobic digestion on every farm can provide a waste management opportunity, whilst producing biogas which can be re-introduced into the production cycle. Additionally, the anaerobic digestion residuals can be converted into pellets and used as natural fertiliser, not made from and entirely without additional harmful chemicals. Utilisation of the available finance schemes, grants and incentives (Table 2) can have the effect that the switch to indoor farming will not necessarily be burdened with costly capital expenditure.

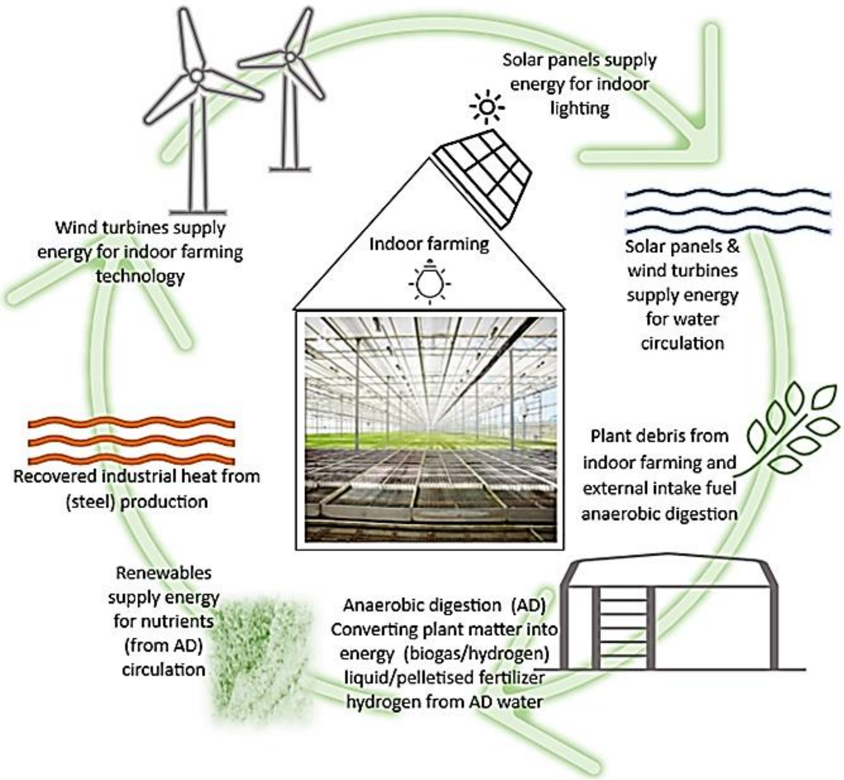

Figure 3 Sustainable indoor farming system.

Besides being a great opportunity to generate own electricity for the indoor farming operations, the measures taken to reduce the carbon footprint can be supported by switching to the providers in Table 4:

Table 4 UK Green energy providers per 09/2024.

Energy provider	**UK Headquarters address**	**Renewable sources**	**Green electricity**	**Green gas**	**Carbon offsetting**
Ecotricity	Lion House, Rowcroft, Stroud, Gloucestershire, GL5 3BY https://www.ecotricity.co.uk/our-green-energy/green-electricity	Wind (98%), solar (0.12%) and hydro (0.7%)	100%	Yes	Yes
Good Energy UK	Monkton Park Offices, Monkton Park Chippenham SN15 1GH https://www.goodenergy.co.uk/	49.41% = Wind. 32.71% = Bio generation. 13.60% = Solar. 4.28% = Hydro.	100%	No	Yes
Green Energy UK	Green Energy (UK) plc Black Swan House, 23 Baldock Street Ware, Herts, SG12 9DH https://www.greenenergyuk.com	Hydro, solar, wind	100%	100%	No
Octopus Energy	UK House, 5th floor, 164-182 Oxford Street, London, W1D 1NN https://octopus.energy/	Anaerobic digestion, solar, wind, hydro	100%	0%	Yes
OUTFOX The Market	16 North Mills, Frog Island, Leicester, Leicestershire, LE3 5DL https://www.outfoxthemarket.co.uk/	Wind	100%	0%	No
OVO Energy	1 Rivergate Temple Quay Bristol BS1 6ED https://www.ovoenergy.com/	Anaerobic digestion 49%, solar 32%, wind 18%, hydro 1%	100%	15%	Yes
SSE Energy Solutions	Inveralmond House, 200 Dunkeld Road, Perth PH1 3AQ https://www.sseenergysolutions.co.uk/business-energy/our-renewable-electricity	Hydro plants and wind farms	100%	No	Yes

2.1.6 Carbon Capture, Avoidance and Utilisation in Indoor Farming

Sheep farming in the UK is usually utilising mountainous areas for hill farming and are set up to be running at a loss, from the start [102, 103]. Without farm subsidies, sheep farmers are not likely to generate enough income to sustain either the farming operation or their families [104, 105]. The average hill farmer has an opportunity here to either diversify to soil farming as carbon capture projects [63, 106-108] and install wind parks, to utilise the areas unsuitable for animal husbandry or arable farming. Additionally, farm buildings can be equipped with solar PV [31] and solar thermal panels, to generate electricity and hot water, which are also partly or entirely subsidised by the schemes shown in Table 2. Additionally, in-house animal husbandry applying the Geomimetic principle [109] and capturing carbon and methane emissions from animal production can be an additional element of circular food production in connection with CCUS, utilising the carbon emissions via Blue Planet's Geomimetic process recycled concrete [109] for the construction of buildings housing meat and dairy production. Furthermore, avoiding the costly and emissions-intense working of the soil and application of fertilisers, fungicides, pesticides, and desiccating agent, a great proportion of harmful substances and emissions can be avoided. As every farming operation is different and there are no records of the chemicals applied, as there is no register to do so, it is difficult to ascertain the volume of CO_2 savings in total. However, as agriculture is known to be responsible for between 20% and 30% of the total CO_2 emissions, globally, the CO_2 savings are deemed substantial [63, 106-108].

3. Discussion and Conclusions

Even the most ardent climate change deniers will have realised by now that floods, droughts and fires and other extreme weather events are destroying crops and are reducing the land zones suitable for food production. The effects of changing seasons and more often occurring extreme weather phenomena are making outdoor food production a partially non-viable enterprise for farmers across the globe. Therefore, it can be argued, food production and generally, the agricultural industry, needs to move their operations indoors, to protect crops and livestock and ensure food security and safety. It could be argued that indoor farming provides industry-changing opportunities for increased asset efficiency, as additional income streams can be generated. Considering that the agricultural sector is responsible for 30% of global CO_2 emissions, this immense opportunity to remove a large proportion of these greenhouse gas emissions cannot and must not be ignored. The SusCiP principle and its components of sustainability, circularity, ecological and socio-economic improvement, as well as production processes designed to only emit water and oxygen are the key elements of this framework and can provide the blueprint to decarbonise production, in all industry sectors. The integration of renewable energy components is based on the thinking that the systems used were produced using green steel, ideally manufactured with the Bio Steel Cycle System in mind. Indoor farming provides multiple opportunities for farm diversification, carbon capture, utilisation and storage and, simultaneously, the chance of improving the socio-economic situation for arable farmers. An additional benefit is the generation of their own organic fertiliser and no need for artificial chemical fertilisers. Moving farming activities and food production indoors can prove to be a challenge, but there are a range of technical solutions at hand, which have been field tested and rolled out on an impressive scale already.

4. Future Research

There are ample opportunities of future research directions for alternative agricultural farming practice, not limited to:

1) Indoor farming viability research in all climatic zones

According to Köppen [110], climates can be categorised into five groups, based on rainfall and temperature:

- Tropical climates (A)
- Dry climates (B)
- Temperate climates (C)
- Continental climates (D)
- Polar climates (E)

2) Floating farming systems in coastal areas and wetlands

There are already some technical solutions for indoor farming and alternative farming practices available, but further research is required to establish which indoor farming system is most suitable, the most effective, secure and viable solution for the local climatic conditions.

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The author did all the research work of this study.

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Competing Interests

The author reports there are no competing interests to declare.

Data Availability Statement

Data used for this study can be made available upon request.

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