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HARMONIZING GROWTH: EXPLORING THE WATER-ENERGY-FOOD NEXUS THROUGH AGRICULTURAL INNOVATION AND CIRCULAR ECONOMY IN A BOREAL ECOSYSTEM

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Abstract

The global commitment to the right to food, enshrined in international legal frameworks such as the UN's Rights to Adequate Food Guidelines, reflects its status as a fundamental human right, an assertion supported by numerous national constitutions and policies (Clapp et al., 2022). Addressing the profound challenge of nourishing the ever-expanding global population underscores the central role of agriculture as the primary vehicle for food provision. However, the production, processing, and distribution of food involve the utilization—often overexploitation—of critical resources, including water, energy, and land, contributing significantly to issues such as pollution and climate change (Mor et al., 2021).

This study delves into the critical interplay between the right to food, agricultural practices, and their environmental repercussions. Highlighting the intricate balance required for sustainable food production, the research aims to contribute to the discourse on navigating the challenges inherent in meeting the nutritional needs of a growing global population. Recognizing the multifaceted importance of agriculture, the paper emphasizes its foundational role in ensuring the existence, survival, and economic well-being not only of humans but also of diverse ecosystems.

Beyond its primary function of providing sustenance, agriculture assumes pivotal roles in sustaining national economies, offering employment opportunities, and fostering livelihoods, particularly in rural areas (World Bank, 2006, 2012). By exploring these dimensions, the study seeks to provide nuanced insights that can inform policies and practices, fostering a harmonious integration of agricultural development with environmental sustainability.

1. Introduction

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The right to food is codified in international legal and policy guidance, such as the UN's Rights to Adequate Food Guidelines and many national constitutions and policies, as a fundamental human right (Clapp et al, 2022). Providing food for the ever-increasing global population is one of the biggest challenge the world was, is and will be facing and agriculture is the main medium through which food is provided. However, in the practice of production, processing, and distribution of food, many resources, including water, energy, and land, are utilized, and sometimes overexploited. This contributes to problems such as pollution and climate change etc. (Mor et al, 2021). The importance of agriculture to humanity and economies cannot be overemphasized, as it is the foundation for the existence, survival, and economic well-being of not only human beings but other creatures. Mainly through the provision of food, agriculture plays other important roles, such as sustaining the economies of most countries, serving as a source of employment, and livelihood, especially for rural folks (World Bank, 2006, 2012).

Despite the crucial role played by agriculture in feeding the world, it doubles as a major culprit for and victim (World Bank, 2012, Fresh Produce Journal, 2015) of some of the world's biggest challenges, including climate change, food wastage, unsustainability, and social, economic, and environmental crises. Agriculture is a sector that strongly and significantly contributes to anthropogenic Greenhouse Gas (GHG) emissions on the planet (Barros et al., 2020; Mor et al., 2021). Agriculture accounts for an estimated 21-37% global GHG emissions according to the Intergovernmental Panel on Climate Change (IPCC 2020, Mor et al., 2021, Clapp et al., 2022), 10% of all GHG emissions in the European Union (Tagarakis et al., 2021) and 13% of GHG emissions through land usage, habitat destruction and fertilizer runoff (Fox et al., 2019). One major sector of agriculture, the dairy, and livestock sector for instance, is responsible for one of the deadliest GHGs, methane. It accounts for approximately 44% of methane emissions globally, 14.5% in the European Union, and 18% in the USA (Mor et al., 2021, Tagarakis et al., 2021, Clapp et al., 2022).

The impact of agriculture is not limited to only GHG emissions. Fox et al., (2019) noted that agriculture is one of "mankind's most ecologically impactful activities, representing 70% of society's water usage' (p. 288) and almost 80% of the world's freshwater (World Bank, 2012). It is common practice in many countries to overexploit and overuse surface and groundwater resources for agricultural purposes, with the attendant destruction of habitats, other creatures, and pollution spread through run-off (Mor et al., 2021). Agriculture contributes to these problems but is also more vulnerable than any other economic sector to the increasing effects of climate change through temperature and rainfall variability etc. (World Bank, 2012) which directly impacts production systems and thus food security (FAO, 2018, Doyon & Juan-Luis, 2021).

Agriculture is thus critical to global food security but also plays a role in contributing to unsustainability and environmental and resource pressures, including water and energy (Zhang et al., 2018, Dai et al., 2018, Fox et a.l, 2019, Unc et al., 2021). This underscores the need for agricultural innovation, which is defined as the "process whereby individuals or organizations bring new or existing products, processes, or ways of organization into use for the first time in a specific context in order to increase effectiveness, competitiveness, resilience toshocks or environmental sustainability and thereby contribute to food security and nutrition, economic development or sustainable natural resource management" (FAO, 2018, p. 3).Agricultural Innovation is not the only way to produce enough food, but it will help to produce sufficient food to support an increasing global population and food demand, and also helpto reduce the impacts resulting from the increase in food demand while sustaining the resource base on which agriculture relies (Vadiee& Martin, 2014, Wichelns, 2017, Mor et al., 2021, Cortes et al., 2022).

The concept of Circular Economy (CE) generally seen as a closed-loop economy (grow-make-use-restore) in contrast to the linear economy (take-make-dispose) model, is receiving much attention in academia, industry, and government/policy circles (Klerkx et al., 2012b, Geisendorf,& Pietrulla, 2018, Moraga et al., 2019, Kristensen & Mosgaard, 2020, Hadley et al., 2021). CE is seen as a promising concept that can contribute to and be implemented in Agricultural Innovation because it promotes “system innovations that aim to design waste, increase resource efficiency, and to achieve a better balance between the economy, society, and environment (Kristensen &Mosgaard, 2020, p.1). CE practices are touted to be advantageous not only to the agro-industrial sector, but also to other sectors of the economy and sustainability, yet only about 9% of the world’s economy is currently circular (Barros et al., 2020).

The two concepts (Agricultural Innovation and CE) have evolved and are evolving (Klerkx et al., 2012b, Meyer J., 2014, Mor et al., 2021), but there seems to be little attention paid to critical analysis of how they are related, their implications on the Water-Energy-Food (WEF) nexus, and how they might be implemented in achieving food security and economic well-being in particular in boreal ecosystems - defined as ecosystems located in the circumpolar northern hemisphere (Keske 2021) contexts. Boreal ecosystem contexts are particularly interesting and potentially fertile grounds for agricultural innovation and CE because climatic conditions among other challenges make them susceptible to food insecurity, and conventional agriculture is somewhat insufficient and a mis-match for such contexts. Hence, implementing agricultural innovation and circular economy in boreal ecosystems can make them net contributors to global food security and GHG emissions (Unc et al., 2021). That “much of the work on CE, including its conceptual work, has been driven by non-academic players” (Kirchherr et al, 2017, p. 222) may help explain this gap in boreal ecosystems. Therefore, this paper provides a critical review of the two concepts mainly through a review of the literature and use of the boreal ecosystem as a case study. It discusses (a) the conceptualization, major trends, debates, critiques, and interrelationships between the concepts of Agricultural Innovation and CE; (b) examine the implications of these two concepts on the WEF nexus in achieving food security and economic well-being in a boreal ecosystem; and (c) explores how these concepts might be implemented in boreal ecosystems.

A critical analysis of the relationships between the concepts and how they might be implemented together will contribute to research and policy efforts towards achieving food security and economic well-being in boreal ecosystems through agricultural innovation and a circular economy, which is cognisant of the WEF nexus.

2. Agricultural Innovation and Circular Economy; conceptualization, debates, criticisms,and trends

2.1. Conceptualizing Agricultural Innovation: Origin, definitions, features, and evolution.

Agricultural Innovation has been defined in different ways (World Bank, 2006, Meyer, 2014; Klerkx et al., 2012b); however, this paper adopts the 2018 definition offered by the Food and Agriculture Organization (FAO) and rendered in the introduction already. This is because the FAO’s definition seems to be the most up-to-date and comprehensive.

Several key components constitute an agricultural innovation system, including (a) an enabling environment including policy, culture, legislation, infrastructure, investment and institutional setup, and market developments (Klerkx et al., 2012b, World Bank, 2006), (b) agricultural research, training and education, and agricultural extension,and (c) bridging institutions, innovation networks, brokers, innovation support systems, public and private sectors, value chains, business, and enterprises (World Bank, 2006, 2012, Klerkx et al., 2012a, Schut et al., 215). Agricultural Innovation there for ecomprises all actors, organizations, and structural conditions at various levels. The presence of these, in addition to innovation capacity and coordination facilitating radical and incremental improvements, can trigger innovation in many ways (World Bank, 2006, Klerkx et al., 2012a, 2012b and Schut et al., 2015). This means that Agricultural Innovation is a co-evolutionary process in which technological, social, economic, and institutional change occurs (Klerkx et al., 2012 a & b, World Bank, 2006) and usually comes out through the organic and dynamic interaction of multiple stakeholders. The appropriate application of agricultural innovation can contribute to sustainability.

However, there are also things that agricultural innovation is not; it is not just a matter of adopting new science or technologies; it is also not inherently good or bad nor value-free, and nonstationary (World Bank, 2006, Klerkx et al., 2012b) but the application of knowledge to achieve desired outcomes (World Bank, 2006, Meyer J., 2014). Agricultural Innovation in a nutshell is an iterative, flexible, and dynamic process that requires balancing of new technical practices and alternative organizing, structures, viewpoints, values, and the interaction between and amongst multiple layers of actors, sectors, institutions, policies, systems, and investment in an enabling environment.

2.2. Major debates and trends in Agricultural Innovation

There have been some major debates and trends in Agricultural Innovation over the years, including how innovation emerges, what motivates it, and approaches to Agricultural Innovation. These trends and debates are discussed below.

2.2.1 How innovation emerges/motivations for innovation.

Over the last 50 years, one of the major debates in Agricultural Innovation has been how innovation emerges, what motivates innovation, and the role of science and technology in fostering innovation. Two main sides of the debate can be identified. The first is the *linear view***,** also known as the*transfer of technology or the science push model*(World Bank, 2006).This viewsees agricultural extension and science as the main drivers of innovation with the belief that basic science and research lead to applied science, which in turn leads to innovation (World Bank, 2006). Agricultural extension connected to national agricultural science systems, for example, has the main objective of enlightening farmers and transferring knowledge to farmers in order to improve productivity (Klerkx et al., 2012a). This view largely implies a one-way driver of innovation from the scientific community to the farmers; and this isn't the case as innovation can occur in and from multiple directions in a non-linear manner.

The other side of the debate is the *innovation system view,* also known as the *market-pull model* which views innovation as an interactive process and recognizes the importance of science and technology (World Bank, 2006). The innovation system view, however, focuses on the interaction between and among research, related activities, attitudes, practices, multiple actors, and the creation of an enabling environment, including institutions, policies, and interventions for innovation to occur (World Bank, 2006, 2012).

These two views seem to correlate with two main trajectories of how innovation develops, depending on who the main actors are, what factors trigger innovation, and the context (World Bank, 2006). The first trajectory is *policy orchestrated innovation system,*mostly led by public actors. The second is *market opportunity-driven innovation system,*which is often led by the private sector or by individual entrepreneurs who identify market opportunities (World Bank, 2006). The policy orchestrated trajectory aligns with the linear transfer of technology view while the market opportunitydriven trajectory aligns with the innovation system view; but the "ultimate phase of development for both views is a dynamic system of innovation which is neither publicly nor privately led but a state of high, agile interaction and collaboration in planning and implementation" (World Bank, 2006, p. 17). The viewpoints of linear and innovation systems have underpinned various approaches to or perspectives on Agricultural Innovation.

2.2.2 Changing Approaches to and for Supporting Agricultural Innovation

A range of approaches, perspectives, paradigms, frameworks, and views on Agricultural Innovation have emerged over the last 50 years and are still evolving (World Bank, 2006, 2012, Klerkx et al., 2012 a & b). These are usually not mutually exclusive, as some co-evolve, exist, or feed into each other (Klerkx et al., 2012 a & b). The number of approaches, perspectives, frameworks, and paradigms used differed among the authors. For instance, the World

Bank (2006, 2012) identified three approaches, and Klerkx et al. (2012a) and (2012b) identified three and four respectively. However, three Agricultural Innovation approaches have been proposed over the years.

The first is the *adoption and diffusion of innovation or transfer of technology* which is a paradigm linked to perspectives such as the National Agricultural Research Systems (NARS) (World Bank, 2006, 2012; Klerkx et al., 2012, a &b). This emerged in the 1960s with a linear underlying idea, in the sense that agricultural research, through technology transfer, is thought to lead to technology adoption and growth in productivity, and innovations spread through communication in social networks of friends, relatives, and neighbors (Klerkx et al., 2012b). In the 1980s, the "NARS framework focused efforts on strengthening the research supply by providing infrastructure, capacity, management, and policy support at the national level" (World Bank, 2012, p.29). The Agricultural Innovation elements of this system are technology packages driven by single-disciplined research pushes and supplied by scientists who are seen as innovators and farmers as adopters, whose behavioral change is the Agricultural Innovation change sought (Klerkx et al., 2012, a & b). The linear technology transfer paradigm has been effective in creating agricultural science capacity and food production transformation in Asia, but was not participatory, was poorly suited for responding to rapidly changing, emerging high-value markets (World Bank, 2006, 2012) and could not address heterogeneity and complexities in production contexts and resource management conflicts (Klerkx et al., 2012b).

These deficiencies in the paradigm necessitate the need for new concepts. Two similar strands of participatory research approaches namely *Farming Systems Research(FSR)* in the 1970s and the 1980s and, more prominently, *Agricultural Knowledge and Information Systems (AKIS)* in the 1990semerged from an extension perspective to respond to the critique, limitations, and undesirable effects of the linear transfer of technology concept (Klerkx et al., 2012 a & b). AKIS according to the authors was based on research pull, collaboration, and participatory technology development, where farmers were not only seen as adaptors of technological innovation but also as experimenters with scientists as collaborators. Multi-disciplinary research and co-production of knowledge and technologies are key elements driven by farmers' demand-pull factors with better fitting co-evolved technologies and empowered farmers as the intended outcomes and changes sought (ibid.). The AKIS framework has been promoted by organizations such as the FAO because it addresses the shortcomings of conventional agricultural education, research, and extension, places emphasis on farmers and their demand for technologies, local capacities, coordination among diverse actors, and the coproduction of knowledge and technologies where policy, science, and technology are defined within social, political, and economic contexts (World Bank, 2006, 2012, Klerkx et al., 2012a). However, it is still critiqued to pay limited attention to the role of the market, private sector, policy, and other disciplines, as well as being rural actors and environment focused, and mechanistic (World Bank, 2006, 2012, Klerkx et al., 2012 a & b). This critique led to the emergence of a systems approach to innovation in agriculture.

Agricultural Innovation Systems (AIS) thinking is the latest perspective that emerged from a research perspective in the 2000s, parallel to AKIS, and influenced by the idea of national systems of innovation (Klerkx et al., 2012b). Its focus is on enhancing the wide range of science and technology operations of businesses, organizations and people that seek out and provide knowledge and technologies as well as the guidelines and methods by which these many actors interact (World Bank, 2012).

The AIS concept goes further in recognizing a broader range of actors and disciplines/sectors involved in innovation, particularly in the private sector (World Bank, 2006) and addresses some of the shortcomings of AKIS by explicitly focusing on the broader network of actors and institutions that affect Agricultural Innovation and giving importance and recognition to the multiplicity of actors beyond agricultural research and extension systems (Klerkx et al., 2012a). AIS adopts a transdisciplinary holistic perspective to create innovation that involves numerous actors, processes, knowledge exchange, collaborations, and change. The key changes sought in AIS are institutional change and innovation capacity, which are necessary for innovation, and the intended outcomes are capacities to innovate, learn, and change (Klerkx et al., 2012 a &b). The AIS perspective therefore faces similar challenges and criticisms as transdisciplinary research, such as managing the complexity of sometimes, conflictive,and divergent interests, values, and perspectives of the multiplicity of actors and institutions and the carious conceptualizations and operationalization of it leaves room for misunderstanding and criticism.

2.3 Criticisms of Agricultural Innovation

Agricultural Innovation as a concept is not one without criticism; however, the critiques are more about and targeted at various perspectives and approaches to Agricultural Innovation. The AIS and AKIS perspectives have received much criticism perhaps because they are the most popular and widely used or adapted perspectives.

One of the main criticisms of the AIS is that it has many different conceptualizations and operationalizations and different orientations towards using the term as a descriptive or normative concept (Klerkx et al., 2012 a & b). Some of the different conceptualizations of AIS include being seen as an infrastructural, process, or functionalist view of innovation. Each of these views emphasizes and is biased towards either creating fertile conditions for innovation to grow and biased towards the public sector (infrastructural view), highlighting the process side of things, and seeing systems in the making (process view), or focusing on whether specific functions are fulfilled or not (functionalist view) (Klerkx et al., 2012b).

These three views (infrastructural, process, and functionalist) of AIS correlate to the root metaphors of the static view on networks, non-linear dynamics, and biological organisms,respectively. There are also different views regarding system boundaries (sector, country, region, technology, or value chain) of innovation systems, as well as different assumptions and conceptions (mostly implicit) about how change in systems comes about, that is, either through competition in a selection environment, through the provision of functionalities, or through coincidence and self-organization (Klerkx et al., 2012a, Schut et al., 2015). Even though not all these viewpoints about AIS may be mutually exclusive, these differences in approaches, trajectories, conceptualizing, and operationalizations open enough room for confusion and misunderstanding (Klerkx et al., 2012b, World Bank, 2006).

AIS has also been criticized for being underutilized (Schut et al., 2015). The underutilization of AIS according to Schut et al., (2015) is because AIS related studies often take narrow instead of holistic focused methods of analysis to complex agricultural problems. Integrated analysis of the multiplicity of dimensions, levels, interactions, and stakeholders of complex agricultural problems must be considered, yet majority of AIS studies take time, and lack clearly delineated system boundaries.Furthermore, Klerkx et al., (2012b) concluded that more conceptual and empirical work needs to be done on AIS because, even though the AIS perspective provides a holistic and comprehensive view of actors and factors which allows for an understanding of the complexity of Agricultural Innovation, its holism is also a pitfall because it opens the Pandora's box for multiple interpretations.

The AKIS perspective is criticized for adopting a "mechanistic hard systems view whereby it was assumed systems exist independently from the observer, and can be analysed, understood, and engineered towards an unambiguous goal" (Klerkx et al, 2012b, p. 462). The mechanistic way of viewing things, concepts, and phenomena is also heavily critiqued by authors such as Fiscus and Fath(2019) for continuing the reductionist conception of lifeenvironment relationships. The AKIS concept is also criticized for being used merely as a strategy to make people think of themselves as being part of a system (Klerkx et al., 2012b) and for being too rural environment-focused and giving little attention to the role of other actors, disciplines, sectors, markets, and policy environment (World Bank, 2006, 2012, Klerkx et al., 2012b).

2.4 Circular Economy

2.4.1 The Concept and evolution of Circular Economy (CE): A brief overview.

The concept of the Circular Economy (CE) emerged from academic and policy discussions, with its roots traced back to Kenneth Boulding's book "The Economics of the Coming Spaceship Earth" in 1966 (Geisendorf & Pietrulla, 2018). The term was coined by Swiss architect and economist Walter Stahel in the 1970s (Mor et al., 2021). CE proposes an industrial system that aims to restore and regenerate resources rather than following a linear "takemake-dispose" model (Geisendorf & Pietrulla, 2018, Mor et al., 2021), Its origins have sparked interest in both academia and policy circles (with China, EU, Japan being pioneers in its adoption), leading to a series of stages in its evolution.

Five distinct stages mark the evolution of CE's conceptualization according to Mor et al., (2021). These are:

(a) Linear Economy Stage: characterised by the industrial revolution, it emphasised resource exploitation, resulting in ecological concerns, (b) Loop-Economy Stage: Awareness grew about environmental issues, leading to actions for protection and concepts such as green economy and sustainability emerged, (c) Coinage of Circular Economy: Walter Stahel's circular model and coining of the circular economy gained prominence, proposing closedlooped systems transforming waste into resources, (d) Ellen MacArthur Foundation's Definition: The foundation's definition emerged in 2012 (widely taken as the most popular definition of CE), focusing on restoration, renewable energy, and waste elimination through better design and (e) Extension to Supply Chain: CE's definition broadened, incorporating supply chain considerations for holistic sustainability.

However, there's a lack of universal consensus on CE's definition, leading to a proliferation of interpretations (Moraga et al., 2019, Kirchherr et al., 2017, Geissdoerfer et al., 2017, Ghisellini et al., 2016*).* Among scholars, the Ellen MacArthur Foundation's definition is widely recognized (Schut et al. 2015, Ghisellini et al, 2016, Geissdoerfer et al. 2017, Kirchherr et al, 2017, Geisendorf & Pietrulla, 2018). It defines CE as an industrial system designed for restoration, regeneration, and waste elimination through innovative materials, products, systems, and business models.

definitional ambiguity and in keeping with Kirchherr's (2017) recommendation, a proposed operational definition combines elements from various sources. It characterizes CE as an economic system adopting contextually relevant circular business models across different levels (macro, meso, micro), utilizing restorative and regenerative design principles in various processes, aiming for a comprehensive sustainability beyond single pillars.

CE principles can be categorized into two groups: (a) R Principles of Frameworks: commonly referred to as waste hierarchies, with the 3R (reduce, reuse, recycle) framework being the most employed and there's been a proliferation in the R principles up to the 10th R now (Kirchherr et al., 2017, Mor et al., 2021) and (b) Systems Perspective: A newer approach emphasizing fundamental systemic shifts across different levels – macro, meso and micro – instead of incremental changes. The macro perspective focuses on transforming the entire industrial structure, the meso perspective targets eco-industrial parks and the micro perspective considers circularity at the product and business levels (Kirchherr et al., 2017, Mor et al., 2021). In recent years, there has been a shift from R frameworks to systems perspective principles, partly influenced by the Ellen MacArthur Foundation's definition. This transition underscores the need for fundamental systemic changes to achieve circularity and sustainability in the economy.

In a nutshell, the Circular Economy concept has its roots in academia and policy discussions, evolving through stages that highlight the shift towards restorative and regenerative economic systems. Despite varying definitions, a growing focus on systemic transformation is evident, with efforts aimed at achieving sustainability across different economic levels.

2.5 Criticisms of CE

The concept of CE is not without criticism; in fact, just like the plethora of definitions of the concept, the criticisms of CE are equally numerous, but here we group them into three main arguments: (1) criticisms around the conceptualization of CE, (2) its relationship(s) to or with other concepts, and (3) CE links and contributions to sustainability.

The first is the issue of too many definitions, meanings, and connotations, and too limiting and narrow principles. Kirchherr et al., (2017) call it the circular economy babble, the idea that CE is conceptually muddled, and that the abundance of conceptualizations of CE constitutes a serious challenge for scholars because it may lead to misleading results and stifle advancement in the field. For example, two of the prominent definitions of CE (i.e., those by the Ellen MacArthur Foundation and the EU are in the view of Geisendorf & Pietrulla (2018), a bit unclear about the condition of waste, as to whether waste is to be minimized or completely avoided.

The waste-oriented view of the 3Rs has been criticized as too limiting and narrow (Kirchherr et al., 2017, Geisendorf & Pietrulla, 2018 and Mor et al., 2021) and probably led to the proliferation of the numbers in the R frames up to the 10^{th} R currently. Some definitions of CE subvert the concept, reducing it to merely recycling, and practitioners' definitions of CE pay little attention to the reduce principle in particular, as it implies a curb on economic growth and consumption, and the "subversion may lead to a continuation of an unsustainable business-asusual model (Kirchherr et al., 2017. p. 227). Furthermore, an oscillation in terms of preference for the scale of implementation of CE is seen between macro and meso levels, with most definitions of CE prior to 2012 focused on macro levels, whereas those after 2012 focused on meso-systems perspectives, and only 40% of definitions according to Kirchherr et al. (2017) conceptualize CE from a systems perspective.

Moreover, CE is often criticized for being blurred, unclear and convoluted with other related concepts (Kirchherr et al., 2017, Geisendorf & Pietrulla, 2018). As mentioned earlier, CE has had some influence and inspiration from other concepts and in fact the main advocate of CE now, the Ellen MacArthur Foundation, promotes the engagement of CE with such other concepts as the blue economy, cradle-to-cradle, closed-loop supply chains, industrial ecology, reverse logistics, resource efficiency, low waste production, biomimicry, and sustainability etc. (Kirchherr et al., 2017). However, Geisendorf and Pietrulla (2018) assert that even though there might be some overlapping ideas and similar goals, they differ in certain aspects and using them interchangeably leads to confusion and unclear definition. The abundance of related terms makes some scholars claim that the CE stands on shaky grounds. This critique is not surprising, especially as there have been attempts to link CE and sustainability, a concept that has itself received scathing criticism, not least on shaky grounds as asserted by Mebratu (1998) and Ekardt (2020)etc.

The final group of criticisms of CE relates to its link with sustainability. CE is often presented as a means to and a condition for sustainable development with beneficial compensatory relationships (Kirchherr et al., 2017, Kristensen & Mosgaard, 2020, and Mor et al., 2021). However, an analysis of the alignment between the three dimensions of sustainability and CE reveals weak, few explicit linkages between the concepts and a bias towards the economic pillar, as most indicators focus on economic aspects, with little attention to the environmental and social aspects (Kirchherr et al., 2017, Geisendorf & Pietrulla, 2018, Kristensen & Mosgaard, 2020). This bias, in the view of Kristensen and Mosgaard (2020), can lead to sub-optimized application of CE and may lead to a narrower approach to sustainability.

2.6 Major Debates & trends in CE

2.6.1 Bioeconomy vs bioeconomics debate

One of the biggest debates in CE is between bioeconomy and bioeconomics. The latter calls for a "societal transformation in which the economy is re-embedded within planetary boundaries and ecological constraints, while the former places a political priority on expanding the use of bioresources and/or biotechnology to emancipate economic development from fossil fuel use" (Allain et al., 2022, p. 62). Bioeconomy is a relatively young but popular paradigm for environmental policies that emphasize the need to substitute fossil resource-based energy and materials and adopt a pathway of economic growth supplied by large amounts of biomass (wood, crops, organic waste, manure, etc.) and the use of biotechnology in multiple sectors (Allain et al., 2022). However, bioeconomics has a 50-year-old history as a scientific paradigm that strives to ground economic theory in biophysical principles and promotes degrowth based on new social norms, structures, and technologies (Allain et al., 2022). These two sides can be likened to the divides of the sustainability debate, that is, the sustainers and transcenders (Fiscus &Fath, 2019) or the Technocrat/economist side and limits to growth/degrowth (Mebratu, 1998) camps, respectively. Even though there are still unanswered questions in this debate, the debate at the moment is unbalanced, with the bioeconomy having the upper hand (Allain et al., 2022).

2.6.2 Debates on transition to bioeconomy

Related to the bioeconomy vs. bioeconomics debate is the one on how to transition towards a bioeconomy in CE because the unanswered questions of that debate have not stopped ideas and talk about a bioeconomic transition; it is, in fact, rapidly gaining grounds (Allain et al., 2022). However, the transition itself is fraught with huge debates, including competing claims about the transition, issues of justice, and policies in the transition. The bioeconomy has been portrayed as a near-panacea, a transformational change to address sustainability issues, spur innovation and sustainable development, replace fossil-based energy and other goods, such as plastics, through the substitution of those goods, while promoting zero-waste circular economies, creating jobs, and valorizing biodiversity (Bastos Lima, 2022). But the bioeconomy transition appears marked not by the delivery of justice in its multiple forms but by general blindness to social and environmental justices in all its forms with overwhelming evidence from the biofuel experiences in emerging bioeconomies such as Brazil, India and Indonesia and Europe (Bastos Lima, 2022) as well as policy and governance issues of coordination and management of the transition temporalities (Allain et al., 2022).

2.6.3 CE link with Sustainable development

Another major trend and area of debate is the connection between CE and sustainable development and sustainability. Researchers have linked or at least tried to connect the CE model and the concept of sustainability. CE is often interpreted as a new business model for a sustainable economy and healthy society (Geisendorf & Pietrulla, 2018), a means to, and a condition for sustainability (Kirchherr et al., 2017, Kristensen & Mosgaard, 2020, & Mor et al., 2021). Mor et al., (2021) asserts that CE is the most effective path for sustainable development for every country, with nine (goals 2, 6, 7, 8, 9, 11, 12, 13, and 15) of the 17 Sustainable Development Goals (SDGs) interlinked to CE. However, given the fact that sustainable development itself is heavily criticized among others for being too vague, conceptually flawed, open to many interpretations, having cacophonous usages, resting on shaky ground, and continuing the extrativist industrial regime (Mebratu, 1998, Meadowcroft, 2017,Ekardt, 2020, Allain et al., 2022), it is no surprise that attempts to link CE and sustainable development encounter many counter arguments. The relationship between the two concepts is found to be weak (Kristensen & Mosgaard, 2020), is hardly explicitly stated in the literature, and is skewed towards the economic dimension of sustainability, neglecting the environmental, social, and intertemporal dimensions (Kirchherr et al., 2017). This skewness is particularly problematic because an understanding that entails only one or two of the three dimensions of sustainable development can result in unsustainability.

2.6.4 Implementation & application of CE

Another major issue in CE is its implementation and application. Even though CE is becoming increasingly important, Kirchherr et al., (2017) believe it has not yet reached the level of implementation, but to Kristensen and Mosgaard (2020), there is a lot of effort from academia, governments, NGOs, and businesses, who are looking for ways to support the transition from a linear economy to a CE. This is evident in the increasing attention paid to the origin, definitions, principles, circular business models, the relationship between CE and sustainability, and policies on CE (Kristensen &Mosgaard, 2020, p. 2). Implementation of CE is said to occur at three main inconsistently used or clearly defined levels: Macro, Meso and Micro (Kirchherr et al, 2017, Geisendorf & Pietrulla, 2018, Kristensen & Mosgaard, 2020).

2.6.5 Measurement, tools, and Indicators

Another area of contention in CE is related to the tools, techniques, and indicators to measure progress towards or away from CE, as they are essential (Geisendorf & Pietrulla, 2018). Yet, "what is to be measured in sense of CE is subject for debate as the definition is ambiguous, and indicators might lead to different or even incoherent conclusions" (Moraga et al, 2019, p. 453). There is neither a generally agreed method of quantifying within the many CE principles of recycling, reusing, remanufacturing, etc. nor at the micro level.

3: Discussion: Relationships, Implications and Implementation of Agricultural Innovation and Circular Economy in a Boreal Ecosystem

Here, we establish the relationships that exist between and among the concepts of agricultural innovationand circular economy (CE), the implications of these concepts on the Water-Energy-Food (WEF) nexus in achieving food security and economic well-being in a boreal ecosystem setting and proposes a framework for how they might be implemented in a boreal ecosystem. This we hope will contribute to filling the gap in the contextualization and usage of the two concepts in a boreal ecosystem setting to achieve food security targets and economic well-being.

3.1 Relationship between agricultural innovation and circular economy

Agricultural Innovation is related to the CE in a number of ways, including but not limited to how they are conceived or defined, conceptualized, approached, implemented, measured, scales, and goals. The definitions of both Agricultural Innovation and CE, (no matter how contested, varied, or many they both and each are), fundamentally advocate for systemic shifts and move away from conventional linear ways of doing things, such as the linear transfer of technology, production, distribution, packaging, consumption, etc., to more circular, systemic, smart, and process based on a focus on ensuring sustainable economic, social, and environmental development (Klerkx et al., 2012b, Meyer J, 2014, Kirchherr et al., 2017, FAO, 2018).

The notion of circularity and application of CE in agriculture is emerging with concepts such as circular agriculture, circular agriculture economy, circular bioeconomy, etc. This is because many sectors of the agricultural industry can be described under the circular agriculture economy concept (related and partly inspired by CE) as a new methodology for addressing agricultural issues (Yaashikaa et al, 2022). CE is geared towards sustainable production and consumption (Duque-Acevedo et al 2020) and the CE is about reduction, reuse, recycling and recovery, and circularity in agriculture (Mor et al., 2021). In terms of scale, both Agricultural Innovation and CE may be triggered, happen, or operate, and consider what needs to happen at the macro (global, entire national economy), meso (regional, sectoral), and micro (individual firm, farmer) levels (World Bank, 2012, Kirchherr et al, 2017, Mor et al, 2021) and involve several formal and informal actors, institutions, and policies. These three levels (macro, meso, and micro) also largely apply in terms of measuring indicators for Agricultural Innovation and CE (Kirchherr et al., 2017, Kristensen & Mosgaard, 2020, Mor et al., 2021).

Agricultural Innovation and CE are related in the sense that they have and continue to evolve. Agricultural Innovation is moving from a linear view of technical change (i.e., from research through extension to the farmer) to an innovation system (Meyer J, 2014), and CE is moving from a linear model (take-make-use-dispose) to a circular model (take/grow-make-use-restore) (Kirchherr et al., 2017; Moraga et al., 2019; Kristensen & Mosgaard, 2020; Barros et al., 2020; Mor et al., 2021). Both concepts in their separate evolutions influence each other (coevolution), and there are similar concepts across them. For instance, there is talk of circular agriculture (Mor et al., 2021, Tagarakis et al, 2021) which, according to Tagarakis et al., (2021), "is a modern agricultural management concept that promotes the reuse of all resources that can be used by the production system itself" (p.1). This is clearly linked to or inspired by the CE concept.

Due to the environmental crisis and especially climate change, both Agricultural Innovation and CE pursue alternative means that will transform current economic and agricultural practices away from the heavy reliance on fossil fuels and other unsustainable ways to more sustainable ones. For instance, most established forestry or agri-food systems produce bio-based alternatives to fossil fuel products (Bastos Lima, 2018). This illustrates the kind of relationship and entanglement between CE and Agricultural Innovation. Both concepts emphasize moving away from conventional monocultures and linear agricultural and economic models towards more diverse, inclusive, and equitable circular production systems (Bastos Lima, 2018, Kirchherr et al., 2017, Moraga et al., 2019, Kristensen & Mosgaard, 2020, Barros et al., 2020, Mor et al., 2021, Bastos Lima, 2022).

Finally, the bioeconomy, which is heavily linked to a CE (Adetoyinbo et al., 2022, Hadley et al., 2021, Allain et al., 2022) is also linked to the emergence of innovations (Allain et al., 2022) including Agricultural Innovation, and most transitions to the bioeconomy rely on products from agriculture (Bastos Lima, 2018). The large amount of waste generated by the agriculture industry has the potential to be exploited and harnessed (Duque-Acevedo et al 2020) as waste management is a key component of CE. Globally, there is massive waste of resources and raw materials used to generate food, but CE inspired "circular agriculture system's primary purpose of judiciously using the resources along the lines of controlled measures to reduce waste by closing the resources' loops is an indication of the innovative application aspect of circularity to the entire food framework, including handling and utilization" (Mor et al, 2021, p. 3). In this way, the two concepts have a symbiotic relationship with each other in terms of inputs and outputs, including bioenergy, biofuels, utilization of agro-industrial waste, and waste heat for heating greenhouses for instance (Fox et al., 2019, Golzar et al., 2021).

CE is seen as one of the steps for the agri-food industry towards sustainability, resource optimization, and dealing with the challenges of resource exhaustion and raw material depletion (Mor et al, 2021). For Yaashikaa et al., (2022), the waste biorefinery process using agro-industrial wastes not only offers energy, but also offers environmentally sustainable modes, which address effective management of waste streams" (p. 1). as well as products such as biofuels, antibiotics, enzymes, phytochemicals, and biofertilizers. Clearly, the concepts are related in many ways and could be useful for achieving food security and economic well-being in boreal ecosystems if implemented well.

3.2 Implications of Agricultural innovation and Circular Economy on Water-Energy-Food (WEF) Nexus in achieving boreal ecosystem food security and economic well-being

In order to establish the implications of Agricultural Innovation and Circular Economy on the Water-EnergyFood (WEF) Nexus and how to achieve boreal ecosystem food security and economic well-being, we first of all give a brief overview of these concepts.

3.2.1 Boreal Ecosystems

Boreal ecosystems are ecosystems "located in the circumpolar northern hemisphere comprising a large amount of land in North America and across the globe" (Keske, 2021, p. 5). Among other factors, cold climatic conditions and poor soil quality in boreal ecosystems adversely affect agricultural production and, hence, food (in)security challenges in boreal ecosystems (Keske, 2021). Converting the soils of boreal ecosystems for agricultural purposes might alter their properties, increase the risk of soil erosion, and accelerate GHG emissions and loss of soil nutrients, but with the right policies, programs, and innovation in agriculture, boreal ecosystems could be a net contributor to global food security (Unc et al, 2021). Therefore, conventional agriculture alone might not be sufficient to achieve food security and economic well-being in such ecosystems; hence, there is a need for agricultural innovation and circular economy.

3.2.2 Water-Energy-Food (WEF) Nexus

Water, food, and energy are interlinked (Zhang et al.,2018, Hamiche et al., 2018) and there are interdependencies across the three sectors (Artioli et al., 2017) as water is needed to produce food and generate energy, and energy is also needed for the production of food and transportation of water. For instance, extreme drought can lead to serious energy and food security problems (Zhang et al., 2018). Agriculture is said to determine levels of food security of the society according to the FAO; however, it is also the largest consumer of water resources in the world, with food systems accounting for 70% of global freshwater withdrawal and 30% of the world's total energy consumption (Zohrabi et al., 2021). The coupled interlinkages between and among water, energy, and food therefore forms a nexus that is delicate. The global demand for all threeis increasing, estimated to increase by over 50% by 2050, (Dai et al, 2018) and driven by factors such as rapid population growth, climate change, urbanization, and overexploitation of resources. The increasing demand increases the pressure on WEF nexus. It is against this background, and in attempts to respond to economic and environmental changes affecting this interconnected relation of water, energy, and food, that the WEF nexus emerged (Zhang et al., 2018, Dai et al., 2018, Sherifinejad et al., 2020)

The water-energy-food nexus has gained attention and popularity in research and policy circles as the security of water, energy, and food has become a challenge in recent years. The World Economic Forum WEF conference in 2008 and the 2011 international nexus conference (Zhang & Vesselinov, 2016, Wichelns,2017, Artioli et al, 2017, 2016, Zhang et al, 2018, Dai et al, 2018, Endo et al, 2020) are some of the key events to have shaped the nexus discourse. However, some authorsbelieve this attention to the nexus is unwarranted, as there is no consensus on the WEF nexus definitions (Wichelns 2017, Zhang et al., 2018, Dai et al., 2018) nor established nexus methodology (Endo et al., 2020).

The concept has varying interpretations in different sectors and contexts, including being interpreted as the interactions among different subsystems (or sectors) within the nexus system or as an analysis approach to quantify the links and trade-offs between the nexus nodes of water, energy, and food, to analyze the coupled human-nature relationships, a resource management tool, an inter-and transdisciplinary approach, a systemic analytical approach, governance framework, a boundary object, and a political process etc. (FAO, 2014, Zhang et al., 2018, Harwood, 2018, Van Gevelt 2020, Endo et al., 2021).

Notwithstanding the differences and vagueness, Zhang et al. (2018) concluded that "the nexus is put forward to call for an integrated management of the three sectors by cross-sector coordination to reduce unexpected sectoral trade-offs and promote the sustainable development of each sector (p. 627), and the handling of complexity, uncertainty, and ambiguity are central to it (Harwood, 2018). The WEF nexus also plays a role in food security in especially boreal ecosystem setting.

3.2.3 Food Security

The WEF nexus has an impact on food security – a situation where and "when all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life" (FAO, 2001, in Clapp, 2014, p. 207). The definition of food security has evolved over the last 50 years since its introduction in the early 1970s with some existing tensions with food sovereignty, but the FAO's definition is the most authoritative and widely used definition (Clapp et al, 2022). Food security is often spoken of in terms of the four pillars of availability, access, utilization, and stability, but Clapp et al. (2022) proposed the addition of two more pillars: agency and sustainability. Food security is a complex problem because it has multiple dimensions with an interplay of diverse factors embedded in interactions across different levels and a multiplicity of actors and stakeholders (Schut et al, 2015), not least the WEF nexus.

3.3 Implications of agricultural innovation and circular innovation on WEF Nexus in achieving boreal ecosystem food security and economic well-being

Agriculture in the boreal and Arctic regions is perceived as both marginal and untapped potential capable of meeting local and international food needs (Unc et al, 2021). Agricultural Innovation and CE have implications for achieving food security and economic well-being in boreal ecosystems, even though there is no single solution for addressing food insecurity problems in and across communities (Zohrabi et al., 2021).

First, reducing food waste through innovative agricultural and circular economic practices can help improve food security and socioeconomic well-being. Food waste is one of the biggest problems in the world; a third (equivalent to 1.3 billion tons annually) of all food produced worldwide is wasted for various reasons (Mor et al., 2021). In a world where energy poverty affects hundreds of millions, especially in rural areas (Bastos Lima, 2022), where about 800 million people do not get adequate food to eat, while approximately 1.5 billion people are overweight (Nafees et al, 2021), it is estimated that 870 million people could be fed if about one-fourth of the food wasted globally is saved (Mor et al, 2021). The appropriate application of innovative agricultural and circular economic practices, such as using waste as organic materials to enhance and produce new products, redesigning, reducing consumption, reusing, recycling, repurposing products, and using innovative business models, could help reduce food waste and insecurity.

In terms of socio-economic well-being in boreal ecosystems, applying innovative agricultural and circular economic practices can lead to improved health for people and the environment, increased employment, income, revenue, and new opportunities, as well as reduced cost/expenditures on managing waste and energy (Ahamed et al., 2019, Mor et al., 2021, Achour et al., 2021). Waste generated from food also leads to the wastage of various resources such as water, land, labor, energy, and capital (Mor et al., 2021). This waste accounts for environmental, social, and economic costs of nearly $700 billion, $900 billion, and $1 trillion per year, respectively (Bordoloi, 2016 as cited in Mor et al., 2021, p. 134). With the proper application of innovative practices such as greenhouses, circularity, and R Principles such as reusing, repair, refurbishing, and recycling materials that are generally regarded as waste etc. (Cuce et al., 2016,Ahamed et al., 2019, Mor et al., 2021) a lot could be salvaged in terms of food security and economic wellbeing in boreal ecosystems.

Another implication of Agricultural Innovation and the CE is ensuring just bioenergy transitions. Agricultural Innovation and the bioeconomy transition can become an “entry point for more comprehensive agri-food system transformation and land-use sustainability, and the four dimensions of environmental justice indicate paths forward” (Bastos Lima, 2022, p.7). This,however, will not be automatic, as others have sounded a note of caution that it could actually perpetuate and promote injustices, especially socially and environmentally (Bastos Lima, 202). Hence, in attempts to achieve food security and economic well-being in boreal ecosystems through Agricultural Innovation and circular economic practices, care must be taken not to continue or exacerbate socioeconomic injustices and exclusions that might already exist.

Furthermore, adopting Agricultural Innovation and circular economic practices may have implications for the notions of space in boreal ecosystems. For instance, in urban areas, this may imply the use of unconventional spaces for agriculture or claiming new spaces for such purposes. Adapting innovative agricultural and circular economic practices such as agricultural use of non-conventional spaces (e.g., roof tops of buildings), reuse of locally soured raw materials and waste in composting, organic farming and hydroponic greenhouses have been proven to shorten food supply chains, promote climate change adaptation, food autonomy and security, reduction in GHGs and decrease pollution in Quebec (Doyon & Juan-Luis, 2021). Circular economic and innovative agricultural practices can therefore bridge the rural-urban divide. But they necessitate a diversity of production models, practices, actors, interests, opinions, environments as well as the removal of local regulatory barriers, such as prohibition of front yard gardening and greenhouses in industrial zones (Doyon & Juan-Luis, 2021).

Related to the above is the governance and policy implications of Agricultural Innovation and CE in achieving food security and economic wellbeing in boreal ecosystems. Managing competing demands/needs is typical of circular economic and Agricultural Innovation implementation and has governance and policy implications. Capacities, institutions, and policies are needed to determine and manage externalities, the distribution of environmental risks, and the institutional capacity for public policy (Kurian, 2017). Competing needs, interests and values is for instance vividly displayed in biofuels, “which was initially advocated to mitigate climate change by shifting away from fossil fuels but has the potential to cause biodiversity loss and food crisis by land use changes, as biomass crops may compete with food for water and land” (Zhang et al., 2018, p. 626). This calls for the systemic integration of policy and governance across sectors and stakeholders, which can increase complexity in ways that are overwhelming or might prevent progress in reaching decisions (Wichelns, 2017, Harwood, 2018).

3.4 How to implement agricultural innovation and circular economy in boreal ecosystem contexts.

The implementation of Agricultural Innovation and CE in a boreal ecosystem is possible with some demonstrable success, as in the case presented by Doyon and Juan-Luis (2022) in Quebec inter alia. However, this would not come without challenges, and stakeholders must see them as opportunities. Researchers, governments, civil society organizations, industry, and communities (including indigenous) from and across relevant sectors at local, national, regional, and global levels need to work together to ensure the successful implementation of Agricultural Innovation and CE in boreal ecosystem contexts, agriculture, and economy because the “sustainable development of northern agriculture requires local solutions supported by locally relevant policies” (Unc et al., 2021, p. 1). Our proposed solution on how Agricultural Innovation and CE can be implemented is a **Circular innovative systems transdisciplinary (CIST) framework** inspired by and synthesized from transdisciplinary research (Hardon et al, 2008), Agricultural Innovation (World Bank, 2006), CE (Ellen MacArthur Foundation, 2016), and nexus thinking (see fig 1). This demands short, medium,and long-term knowledge co-production, dissemination, and application to meet the agricultural and economic needs of boreal ecosystems without compromising the environment, ecosystems, and communities, as well as the systemic transformation of agriculture and economy in boreal ecosystems from linear to circular. The five main components of this framework are discussed below.

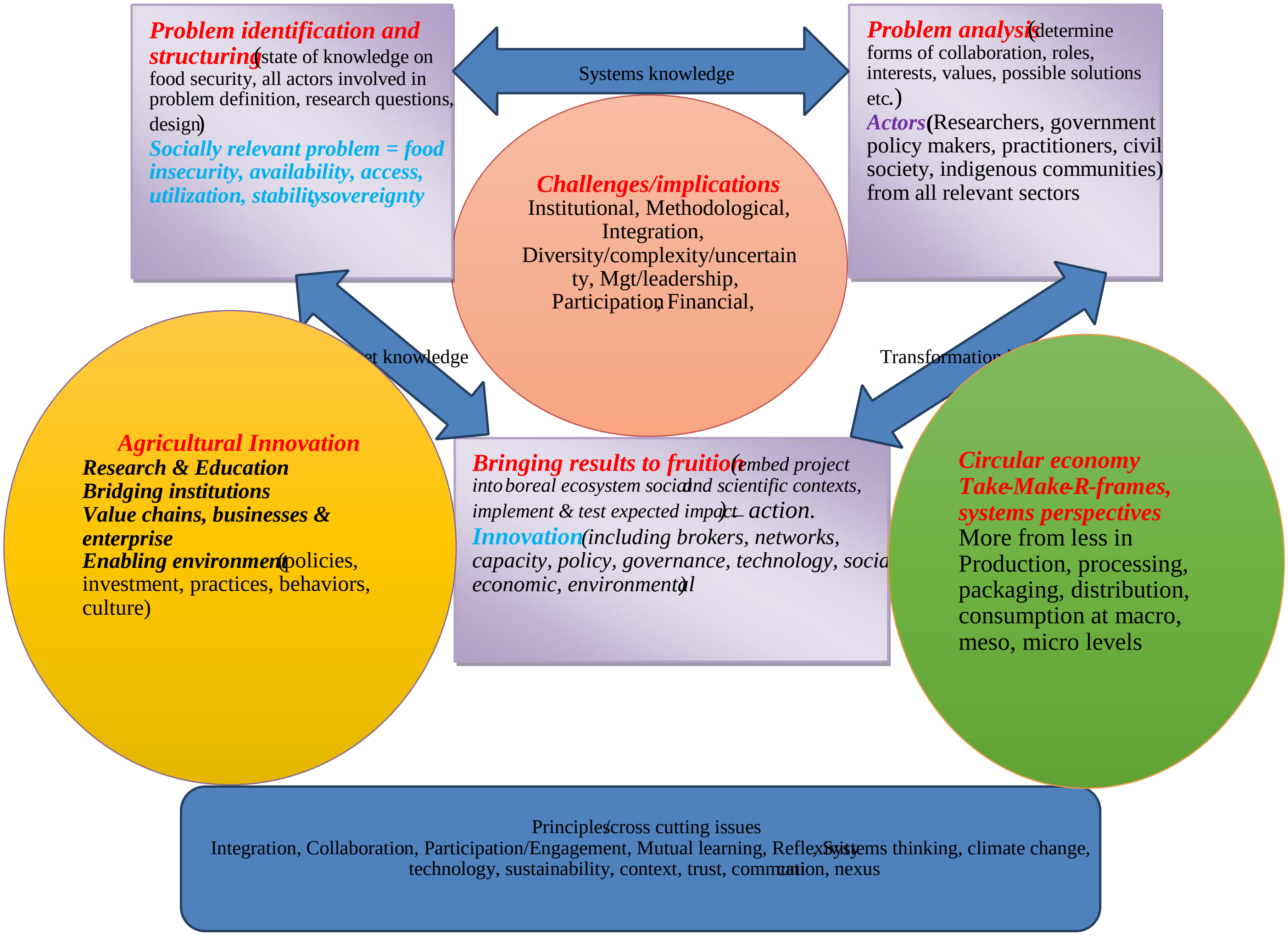

Figure 1: Circular innovative systems transdisciplinary framework: Inspired by TDR (Hardon et al, 2008), AI

- **Knowledge production and application (inter and transdisciplinary approaches)**–learning and capacity building with a focus on innovation rather than production, facilitation interaction, and learning of and from different knowledge sources (including indigenous) and linking for accessing knowledge (in its various forms including systems, target, and transformational) and learning in many forms including partnerships, commercial transactions, or knowledge services–is fundamental (World Bank, 2006, 2012, Hardon et al, 2008, Endo et al, 2020). This would inform and guide problem identification, analysis, and action processes in boreal ecosystems.

Progressive Governance and policy is needed in boreal ecosystems to that create an enabling environment,

- investments in institutions, innovation, leadership, and engagement to spur innovation-oriented attitudes and practices, interactions of behavioral patterns, and innovation triggers to engage new actors, voices, and roles, and ensure the real inclusion of all stakeholders and communities in the development, implementation, evaluation, and redoing of agriculture in boreal ecosystems better.

- **Adoption and implementation of Appropriate AI & CE practices, strategies**- These must be contextualize in the specific boreal ecosystem setting including business models, and technologies that are suitable for boreal ecosystems such as smart agriculture, circular agriculture, vertical farming, greenhouse farming, renewable energy, etc. This can provide benefits including but not limited to reduction in fossil fuel dependence, reduction in cost of energy, water demand, improved yields, food security, healthy and new job opportunities.

- **Systems design & thinking** (for complexity, uncertainty) – employing systems design and thinking driven by clear compelling shared visions, goals, and purposes for the utilization of CE and Agricultural Innovation in a boreal ecosystem's food security and economic well-being can build the ability to cope with change, uncertainty, sticky information, facilitate networks of innovation, and navigate complexity. Food security and economic wellbeing in boreal ecosystems are complex and requires systemic thinking and design.
- **Cross cutting issues & principles** – Above all, these issues and principles must permeate all other components of the framework. Integration, Collaboration, Participation/Engagement, Mutual learning, Reflexivity, climate change, technology, sustainability, context, trust, communication, and nexus approach. As can be seen from the figure, all components interact and feed into each other to make the system functional to the needs of boreal ecosystems.
- **Dealing with challenges and implications of the CIST Framework –** implementing the circular innovative systems transdisciplinary (CIST) framework in a boreal ecosystem context comes with its challenges and implications that must be addressed. These challenges and implications range from institutional, methodological, complexity, leadership, and management to finance and integration, participation, and accounting for diversity and uncertainty. The transdisciplinary approach alone is not easy to meaningfully implement, and to add other layers of innovation, circularity, and systems design, and thinking implies that the level of complexity becomes even more. However, if implemented effectively, the CIST framework offers a lens that can ensure and meet the food security targets of boreal ecosystems without compromising the WEF nexus, the environment, and society at large. Complexity is simplified once all stakeholders understand and appreciate each aspect of the framework and see them as fundamental to addressing the complex problems confronting them.

4. Conclusion

The concepts of Agricultural innovation (AI) and circular economy (CE) from this review are related in many useful ways. Despite the huge trendy debates and criticisms of the concepts, their appropriate application together can contribute immensely towards achieving food security and economic well-being in boreal ecosystems. However, doing so would not come without challenges. This study proposes a Circular innovative systems trans disciplinary framework with five key components on how to implement Agricultural Innovation and CE in achieving food security in a boreal ecosystem context and its implications on the Water-Energy-Food (WEF) nexus. The concepts are not perfect; they are evolving, and much work still needs to be done, including developing research methods capable of accounting for debatable aspects and nuances, detailed understanding of how to measure and document progress towards a CE in boreal ecosystem contexts, and how to navigate the complexities of Agricultural Innovation, CE and the WEF nexus and bringing diverse stakeholders to the table.

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Ethical Compliance

This manuscript is a review work based on already published information. No human subjects were involved in primary data collection in the production of this manuscript.

Conflict of Interest declaration

The authors declare that they have NO affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

References

Achour, Y., Ouammi, A., Zejli, D. (2021). Technological progresses in modern sustainable greenhouses cultivation as the path towards precision agriculture. *Renewable and Sustainable Energy Reviews*, 147 (2021), 111251. https://doi.org/10.1016/j.rser.2021.111251

Ahamed, Md S., Guo, H., Tanino, K. (2019). Energy saving techniques for reducing the heating cost of conventional greenhouses. *Biosystems Engineering*, 178 (2019): 9-33.

Allain, Ruault, J.-F., Moraine, M., &Madelrieux, S. (2022). The "bioeconomics vs bioeconomy" debate: Beyond criticism, advancing research fronts. Environmental Innovation and Societal Transitions, 42, 58–73. https://doi.org/10.1016/j.eist.2021.11.004

Artioli, F., Acuto, M., McArthur, J. (2017). The water-energy-food nexus: An integration agenda and implications for urban governance. Political Geography, 61 (2017): 215-223. https://doi.org/10.1016/j.polgeo.2017.08.009

Barros, Murillo Vetroni, Rodrigo Salvador, Antonio Carlos de Francisco, Cassiano Moro Piekarski, Mapping of research lines on circular economy practices in agriculture: From waste to energy, *Renewable and Sustainable Energy Reviews*, Volume 131, 2020

Bastos Lima. (2022). Just transition towards a bioeconomy: Four dimensions in Brazil, India and Indonesia. Forest Policy and Economics, 136. https://doi.org/10.1016/j.forpol.2021.102684

Carter, K. L., &Vodden, K. (2017). Applicability of territorial innovation models to declining resource-based regions:

Lessons from the Northern Peninsula of Newfoundland. The Journal of Rural and Community Development, 12 (2/3), 74-92.

Clapp, J. 2014. Food security and food sovereignty: Getting past the binary. *Dialogues in Human Geography*. 4 (2) pp. 206-211

Clapp, Jennifer, William G. Moseley, Barbara Burlingame, Paola Termine, Viewpoint: The case for a six-dimensional food security framework, *Food Policy*, Volume 106, 2022

Cortes, S.T., Bugtai, V.H., Lampawog, E.E. et al. (2022). Assessing problems and prospects of urban agriculture in cebu city, philippines: towards developing action plans. Journal of Nusantara Studies (JONUS), 7(1), 264-291. https://doi.org/10.24200/jonus.vol7iss1pp264-291.

Cuce, E., Harjunowibowo, D., Cuce, P.M. (2016). Renewable and sustainable energy saving strategies for greenhouse systems: A comprehensive review. *Renewable and Sustainable Energy Reviews*, 64 (2016): 34-59.https://doi.org/10.1016/j.rser.2016.05.077

Dai, J., Wu, S., Han, G., Weinberg, J., Xie, X., Wu, X., Song, X., Jia, B., Xue, W., Yang, Q. (2018). Water-energy nexus: A review of methods and tools for macro-assessment. Applied Energy, 210 (2018): 393-408. https://doi.org/10.1016/j.apenergy.2017.08.243

Dallendörfer, Dieken, S., Henseleit, M., Siekmann, F., &Venghaus, S. (2022). Investigating citizens' perceptions of the bioeconomy in Germany – High support but little understanding. Sustainable Production and Consumption, 30, 16–30. https://doi.org/10.1016/j.spc.2021.11.009

Doyon, Mélanie, and Juan-Luis Klein. 2021. "Non-Conventional Agricultural Spaces and Climate Change: The Cases of Le Grenierboréal and Lufa Farms in Quebec, Canada" *Climate* 9, no. 10: 148. https://doi.org/10.3390/cli9100148

Duque-Acevedo, M.; Belmonte-Ureña, L.J.; Plaza-Úbeda, J.A.; Camacho-Ferre, F. The Management of Agricultural Waste Biomass in the Framework of Circular Economy and Bioeconomy: An Opportunity for Greenhouse

Agriculture in Southeast Spain. *Agronomy* **2020**, *10*, 489. https://doi.org/10.3390/agronomy10040489 Ekardt, F., 2020. Sustainability Transformation, Governance, Ethics, Law, Springer Nature Switzerland.

Endo, A., Yamada, M., Miyashita, Y., Sugimoto, R., Ishii, A., Nishijima, J., Fujii, M., Kato, T., Hamamoto, H., Kimura, M., Kumazawa, T., Qi, J. (2020). Dynamics of water–energy–food nexus methodology, methods, and tools. Current Opinion in Environmental Science & Health, 13 (2020): 46-60. https://doi.org/10.1016/j.coesh.2019.10.004

Fabrizio, E. (2012). Energy reduction measures in agricultural greenhouses heating: Envelope, systems and solar energy collection. *Energy and Buildings*, Volume 53, 2012, pp. 57-63

FAO, 2014. The Water-energy-food Nexus: a New Approach in Support of Food Security and Sustainable Agriculture. Food Agric. Organ, Rome.

FAO. (2018). 20 Success Stories of Agricultural Innovation from the Innovation Fair. 24. Retrieved from http://www.fao.org/3/CA2588EN/ca2588en.pdf#page=11 03/11/2022

Firfiris, V.K., Fragos, V.P., Kotsopoulos, T.A., Nikita-Martzopoulou, C. (2020). Energy and environmental analysis of an innovative greenhouse structure towards frost prevention and heating needs conservation. *Sustainable Energy Technologies and Assessments*, 40 (2020), 100750. https://doi.org/10.1016/j.seta.2020.100750

Fiscus, D.A., Fath, B.D., 2019. Foundations for Sustainability. A Coherent Framework of Life-Environment Relations, London: Elsevier Academic Press.

Forkuor, G., Amponsah, W., Oteng-Darko, P., Osei, G. (2022). Safeguarding food security through large-scale adoption of agricultural production technologies: The case of greenhouse farming in Ghana. Cleaner Engineering and Technology, 6 (2022), 100384. https://doi.org/10.1016/j.clet.2021.100384

Fox, J.A, Adriaanse, P., Stacey, N.T. (2019). Greenhouse energy management: The thermal interaction of greenhouses with the ground. Journal of Cleaner Production, 235 (2019): 288-296. https://doi.org/10.1016/j.jclepro.2019.06.344

Geisendorf, S., & Pietrulla, F. (2018). The circular economy and circular economic concepts – a literature analysis and redefinition. *Thunderbird Int Bus Rev.*, 771-782.

Golzar, F., Heeren, N., Hellweg, S., Roshandel, R. (2021). Optimisation of energy-efficient greenhouses based on an integrated energy demand-yield production model. Biosystems Engineering, Volume 202, 2021, pp. 1-15. https://doi.org/10.1016/j.biosystemseng.2020.11.012

Hadley Kershaw, Hartley, S., McLeod, C., & Polson, P. (2021). The Sustainable Path to a Circular Bioeconomy. Trends in Biotechnology (Regular Ed.), 39(6), 542–545. https://doi.org/10.1016/j.tibtech.2020.10.015

Hamiche, A.M., Stambouli, A.B., Flazi, S. (2016). A review of the water-energy nexus. Renewable and Sustainable Energy Reviews, 65 (2016): 319-331. https://doi.org/10.1016/j.rser.2016.07.020

Harwood, S.A. (2018). In search of a (WEF) nexus approach. Environmental Science & Policy, 83 (2018): 79-85. https://doi.org/10.1016/j.envsci.2018.01.020

Kaddoura, S., El Khatib, S. (2017). Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. Environmental Science & Policy, 77 (2017): 114-121. https://doi.org/10.1016/j.envsci.2017.07.007

Keske, C. (2021). The connectivity of food security, food sovereignty, and food justice in boreal ecosystems: The case of Saint-Pierre and Miquelon. UC Merced. Retrieved from https://escholarship.org/uc/item/3t6995jn, on 02/10/2022

Kirchherr, J., Reike, D., &Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation & Recycling*, 221-232.

Klerkx, L., Schut, M., Leeuwis, C., Kilelu, C., 2012a. Advances in knowledge brokering in the agricultural sector: towards innovation system facilitation. IDS Bull. 43, 53–60.

Klerkx, L., van Mierlo, B., Leeuwis, C., 2012b. Evolution of systems approaches to agricultural innovation: Concepts, analysis and interventions. In: Darnhofer, I., Gibbon, D., Dedieu, B. (Eds.), Farming Systems Research into the 21st Century: The New Dynamic. Springer, Dordrecht, pp. 457–483.

Kristensen, H.S., Mosgaard, M.A., 2020. A review of micro level indicators for a circular economy – Moving away from the three dimensions of sustainability? *J.Clean. Prod.* 243, 11853.

Kurian, M. (2017). The water-energy-food nexus: Trade-offs, thresholds and transdisciplinary approaches to sustainable development. Environmental Science & Policy, 68 (2017): 97-106. https://doi.org/10.1016/j.envsci.2016.11.006

Lam, Jose and Carter, Ken and McGillis, Louise and Pike, Candice and McCahon, Marion and Vodden, Kelly (2013) Networks for Business Innovation (Corner Brook). Project Report. Harris Centre.

Marco Marchetti, Matteo Vizzarri, Bruno Lasserre, Lorenzo Sallustio, & Angela Tavone. (2015). Natural capital and bioeconomy: challenges and opportunities for forestry. A*nnals of Silvicultural Research,* 38(2), 62–73. https://doi.org/10.12899/asr-1013

Meadowcroft, J. 2017. Sustainable development, limits and growth: reflections on the conundrum, Chapter 3 in volume Handbook on Growth and Sustainability, edited by Peter A Victor and Brett Dolter, Edward Elgar Publishing.

Mebratu, D., 1998, "Sustainability and Sustainable Development: Historical and Conceptual Review", Environ Impact Assess Rev.,18:493–520.

Meyer, J. D. (2014). Agricultural Innovation: Common understanding the upcoming SOFA 2014. 1–12. Retrieved from http://www.fao.org/fileadmin/templates/tci/pdf/Investment_Days_2012_1st_day/Session_I/JulienDeMeyer.pdf

Mor, Panghal, A., & Kumar, V. (2021). *Challenges and Opportunities of Circular Economy in Agri-Food Sector Rethinking Waste* (1st ed. 2021.). Springer Singapore. https://doi.org/10.1007/978-981-16-3791-9

Moraga, G., Huysvelda, S., Mathieuxc, F., Blenginic, G.A., Alaertsd, L., Ackerd, K., Meesterb, S., Dewulfa, J., 2019. Circular economy indicators: What do they measure? *Resources, Conservation and Recycling,* vol. 146. Pp. 452–461.

Philp. (2018). The bioeconomy, the challenge of the century for policy makers. New Biotechnology, 40(Pt A), 11–19. https://doi.org/10.1016/j.nbt.2017.04.004

Schut, M., L. Klerkx, J. Rodenburg, J. Kayeke, L. Hinnou, C. Raboanarielina, P. Adegbola, A. van Ast, L. Bastiaans (2015). RAAIS: Rapid Appraisal of Agricultural Innovation Systems (Part I). A diagnostic tool for integrated analysis of complex problems and innovation capacity. *Agricultural Systems* 132 (2015) 1–11

Shamshiri, R., Kalantari, F., Ting, K.C., Thorp, K.R., Hameed, I. A., Weltzien, C., ... & Shad, Z. M. (2018). Advances in greenhouse automation and controlled environment agriculture: A transition to plant factories and urban agriculture. International Journal of Agricultural and Biological Engineering, 11 (1): 1-22. DOI10.25165/j.ijabe.20181101.3210

Sharifinejad, A., Zahraie, B., Majed, V., Ravar, Z., Hassani, Y. (2020). Economic analysis of Water-Food-Energy Nexus in Gavkhuni basin in Iran. Journal of Hydro-environment Research, 31 (2020): 14-25. https://doi.org/10.1016/j.jher.2020.03.001

Shashank Kumar, Rakesh D. Raut, Kirti Nayal, Sascha Kraus, Vinay Surendra Yadav, Balkrishna E. Narkhede, To identify industry 4.0 and circular economy adoption barriers in the agriculture supply chain by using ISMANP, *Journal of Cleaner Production*, Volume 293, 2021, 126023

Tagarakis, A.C., Dordas, C., Lampridi, M., Kateris, D., Bochtis, D. (2021). A Smart Farming System for Circular Agriculture. Engineering Proceedings, 2021; 9(1):10. https://doi.org/10.3390/engproc2021009010

Unc A, Altdorff D, Abakumov E, Adl S, Baldursson S, Bechtold M, Cattani DJ, Firbank LG, Grand S, Guðjónsdóttir M, Kallenbach C, Kedir AJ, Li P, McKenzie DB, Misra D, Nagano H, Neher DA, Niemi J, Oelbermann M, Overgård Lehmann J, Parsons D, Quideau S, Sharkhuu A, Smreczak B, Sorvali J, Vallotton JD, Whalen JK,

Young EH, Zhang M and Borchard N (2021) Expansion of Agriculture in Northern Cold-Climate Regions: A Cross-Sectoral Perspective on Opportunities and Challenges. Front. Sustain. Food Syst. 5:663448. doi: 10.3389/fsufs.2021.663448

Vadiee, A., Martin, V. (2014). Energy management strategies for commercial greenhouses. Applied Energy, 114 (2014): 880-888. https://doi.org/10.1016/j.apenergy.2013.08.089

Van Gevelt, T. (2020). The water–energy–food nexus: bridging the science–policy divide. Current Opinion in Environmental Science & Health, 13 (2020): 6-10. https://doi.org/10.1016/j.coesh.2019.09.008

Wichelns, D. (2017). The water-energy-food nexus: Is the increasing attention warranted, from either a research or policy perspective? Environmental Science & Policy, 69 (2017): 113-123. https://doi.org/10.1016/j.envsci.2016.12.018

World Bank, 2006. Enhancing agricultural Innovation: How to Go Beyond the Strengthening of Research Systems.WorldBank,Washington, DC, p. 118.

World Bank, 2012. Agricultural Innovation Systems: An Investment Sourcebook. The World Bank,Washington, DC.

Yaashikaa, Senthil Kumar, P., &Varjani, S. (2022). Valorization of agro-industrial wastes for biorefinery process and circular bioeconomy: A critical review. Bioresource Technology, 343, 126126–126126. https://doi.org/10.1016/j.biortech.2021.126126

Zhang, C., Chen, X., Li, Y., Ding, W., Fu, G. (2018). Water-energy-food nexus:vp 0-p; Concepts, questions and methodologies. Journal of Cleaner Production, 195 (2018): 625-639. https://doi.org/10.1016/j.jclepro.2018.05.19

Zhang, X., Vesselinov, V.V. (2016). Energy-water nexus: Balancing the trade offs between two-level decision makers. Applied Energy, 183 (2016): 77-87. https://doi.org/10.1016/j.apenergy.2016.08.156

Zohrabi, N. et al., (2021). Towards Sustainable Food Security: An Interdisciplinary Approach. 2021 IEEE

SmartWorld, Ubiquitous Intelligence & Computing, Advanced & Trusted Computing, Scalable Computing & Communications, Internet of People and Smart City Innovation

(SmartWorld/SCALCOM/UIC/ATC/IOP/SCI), 2021, pp. 463-470. doi: 10.1109/SWC50871.2021.00069