SN Soc Sci (2024) 4:73
https://doi.org/10.1007/s43545-024-00869-x

ORIGINAL PAPER

Implementing the water-energy-food nexus approach to create synergies and reduce tradeoffs between the Sustainable Development Goals

Anna-Karin Margareta Andersson[1]

Received: 18 April 2023 / Accepted: 26 February 2024 / Published online: 11 March 2024

Abstract

The Food-Energy-Water nexus approach to resource governance is a paradigm-shifting approach that moves away from "siloed" resource management and pursues integration and holistic planning between food, energy, and water governance. The Food-Energy-Water nexus approach carries the potential to increase synergies and reduce tradeoffs between the Sustainable Development Goals. However, theoretical challenges remain, and practical implementations of the nexus approach have lagged. The purpose of the article is to respond to the theoretical challenges and the need for practical implementations. The article first outlines the relationship between the Food-Energy-Water nexus approach and the Sustainable Development Goals. It then analyzes the relationship between the Sustainable Development Goals, human rights, and the capability approach, an influential account of well-being. I then discuss how the Food-Energy-Water nexus approach, in alignment with the capability approach, can contribute to trade-off reductions and synergies between the Sustainable Development Goals. I finally discuss an outline of a context-specific implementation model for a Food-Energy-Water nexus approach capable of mapping and quantifying carbon footprints creating synergies and reducing tradeoffs between the Sustainable Development Goals. A carbon capture and utilization project in the Arctic serves as a test case. Important policy implications of the study include a criterion for what it means to "optimize" the "output" of an algae cultivation system. This criterion is a tool for adjudication between stakeholders' conflicting priorities.

Keywords The food-water-energy nexus approach · The Sustainable Development Goals · The capability approach · Human rights · Aquaculture industry

✉ Anna-Karin Margareta Andersson
anna-karin.m.andersson@uit.no

[1] The Norwegian College of Fishery Sciences, Faculty of Biosciences, Fisheries and Economics, UiT – The Arctic University of Norway, Muninbakken 21, Tromsø, N-9037, Norway

Introduction

In 2015, the United Nations introduced the 17 Sustainable Development Goals to address significant human development challenges on a global scale. Amongst these goals are "food security" (goal 2), "clean water" and "sanitation" (goal 6), and "clean, affordable energy" (goal 7) (United Nations 2015, p. 18). Increasing pressure on these resources due to increasing global population, urbanization, changed lifestyles and diets, and climate change (Hoff 2011; World Economic Forum 2011; Food and Agriculture Organization of the United Nations 2014a, b; International Renewable Energy Agency 2015; Unesco World Water Assessment Programme 2023; Segovia-Hernández et al. 2023) necessitates tradeoffs between the Sustainable Development Goals. The terms "scenario" and "pathways" play central roles in the Sustainable Development agenda. The Intergovernmental Panel on Climate Change (IPCC) characterizes these terms as follows: "Scenarios are comprehensive, plausible, integrated descriptions of possible futures based on specified, internally consistent underlying assumptions, with pathways often used to describe the clear temporal evolution of specific scenario aspects or goal-oriented scenarios" (Intergovernmental panel on climate change 2018, p. 98). All climate pathways in the literature involve failure to simultaneously accommodate all the Sustainable Development Goals (Intergovernmental panel on climate change 2018, p. 467). The Food-Energy-Water nexus approach to resource governance has been advocated as a paradigm-shifting approach to resource governance. It moves away from "siloed" resource management and pursues integration and holistic planning between food, energy, and water governance (Hoff 2018). The Food-Energy-Water nexus is closely connected with all the Sustainable Development Goals, and particularly with goals 2, 6, and 7 (Liu et al. 2018, p. 471). It has been advocated as a tool to increase synergies and reduce tradeoffs between the Sustainable Development Goals. "Synergies" has been defined by the Merriam-Webster Dictionary as "mutually advantageous conjunction … of distinct … elements (such as resources or efforts)." Although the nexus approach is the subject of intense research interest, theoretical challenges remain, and practical implementations of the nexus approach have lagged. The limited amounts of implementation projects have focused mainly on irrigation projects in the Middle East and African countries. Hoff et al. (2019) present 5 case studies of nexus implementations from Jordan, Lebanon, and Morocco. The five cases are drip irrigation and solar water pumping for irrigation in Morocco; solar desalination and utilization of desalinated water for the production of biomass, and water, land, and energy management at the municipal level in Jordan; and such management at farm level in Lebanon (Hoff et al. 2019, p. 4). The authors summarize the nexus gains of these projects as follows: Drip irrigation can make agricultural water and energy use more efficient: and the level of food production can be maintained using less water and less energy required for pumping. Using solar energy instead of fossil fuel for pumping can potentially reduce costs and reduce the need to import fossil energy. Benefits include climate change mitigation, potentially reduced irrigation costs, and increased income for farmers (Hoff et al. 2019, p. 6).

Implementation projects within the aquaculture industry have remained less pursued despite their potential positive impact. The moral grounding and conceptual analysis of the Sustainable Development Goals are also urgent areas of research. The objective of this article is to contribute to filling this significant research gap. It does so by analyzing and developing the conceptual and normative relationships between the Sustainable Development Goals, the closely related human rights framework, and the capability approach. The capability approach is an influential, paradigm-shifting account of quality of life. The article outlines and examines a context-specific implementation model for a Food-Energy-Water nexus approach. This model can create synergies and reduce tradeoffs between the Sustainable Development Goals in the aquaculture industry in the Arctic. Specifically, the article discusses the model's potential for mapping and quantification of carbon footprints and the creation of synergies and reduction of tradeoffs between the Sustainable Development Goals. A carbon capture and utilization project in collaboration between UiT The Arctic University of Norway and local ferrosilicon producer Finnfjord AS based in northern Norway could serve as a test case for the model. This article aims to contribute to the operationalization of the Sustainable Development Goals in this specific geographic context. The main novel insights of the article are: The article responds to the call for conceptual development of the Water-Energy-Food nexus approach through analysis of the conceptual relationships between concepts that are closely related to the Water-Energy-Food nexus: The Sustainable Development Goals, human rights, and the capability approach.

The article responds to the call for context-specific implementation models and responds specifically to the call for implementation models for algae cultivation within the aquaculture industry.

The article is structured as follows: In the first and second sections, I begin by outlining the relationship between the Food-Energy-Water nexus approach and the Sustainable Development Goals. In the third, fourth, fifth, and sixth sections, I then analyze the relationship between the Sustainable Development Goals, human rights, and the capability approach. The capability approach is an influential account of well-being. It interprets the quality of life in terms of the ability to function in characteristically human ways. I focus specifically on an influential version of the capability approach that identifies characteristically human ways of functioning that, if nourished or neglected, can affect other characteristically human ways of functioning positively or adversely. In the seventh section, I then discuss how the Food-Energy-Water nexus approach, in alignment with this version of the capability approach, can contribute to trade-off reductions and synergies between the Sustainable Development Goals. In sections eight, nine, ten and eleven, I finally discuss an outline of a context-specific implementation model for a Food-Energy-Water nexus approach. Section 12 comprises discussions and an outline of policy implications. This model is capable of mapping and quantifying carbon footprints creating synergies and reducing tradeoffs between the Sustainable Development Goals for the carbon capture and utilization project in the Arctic. The European Commission (2016) stresses the "importance of working at the

local level, applying local solutions and decentralized approaches, as well as the inclusion of social aspects" (European Commission 2016, p. 68), and "the importance of implementation, i.e., of going from vision to action in the implementation of a nexus" (European Commission 2016, p. 73). Nexus approaches should integrate social and ecological sciences (Liu et al. 2007). In addition, there is a need to explicitly link nexus solutions to research that quantifies the fulfillment of Sustainable Development (Xu et al. 2020). This article responds to this recommendation of research focus.

Methodology

The research methodology is a systematic review and analysis of published peer-reviewed articles and books. The articles were identified by searches of keywords (The food-water-energy nexus approach; The Sustainable Development Goals; The capability approach; human rights; aquaculture industry) in major databases (Scopus, Web of Science) and broader internet searches. The abstracts of the articles were screened. Based on the screening of the abstracts, relevant articles were read in full. The article combines conceptual analysis to develop a conceptual framework with a discussion of how the conceptual framework can be applied to a research and development project.

The relationship between the food-energy-water nexus approach and the Sustainable Development Goals

This section outlines the Food-Energy-Water nexus approach and its relationship to the Sustainable Development Goals. In short, the approach aims to map the interactive links between food, energy, and water governance. The information will be used to increase the efficiency of food energy and water governance, reduce tradeoffs, and increase synergies between the Sustainable Development Goals. The 17 Sustainable Development Goals introduced by the United Nations in the 2015 report *Transforming Our World: the 2030 Agenda for Sustainable Development* (United Nations 2015) are crafted to meet significant global challenges. The goals are benchmarks for global human development in areas including food security, access to affordable, clean energy, water, and sanitation. These goals relate directly to the Food-Energy-Water nexus (Liu et al. 2018, p. 471).

Liu et al. (2018) explicitly emphasize the potential synergies between the Food-Energy-Water nexus and the SDGs. They state:

> The food–energy–water nexus approach can influence the achievement of all SDGs directly or indirectly by strengthening synergies, reducing trade-offs, and creating cascading effects beyond food, energy, and water sectors. (Liu et al. 2018, p. 468)

They highlight some potential links:

> Some indices in nexus studies overlap with SDG indicators, such as CO_2 emissions and environmental footprints, facilitating direct connections between nexus research and SDGs. (Liu et al. 2018, p. 471)

They provide even more explicit descriptions of the links between the nexus and specific SDGs:

> Nexus approaches can help achieve SDGs because SDG goals are interconnected and linked with the sectors of a particular nexus. For example, the food–energy–water nexus is directly linked with SDGs 2 (zero hunger), 6 (clean water and sanitation), and 7 (affordable and clean energy). This nexus also directly or indirectly affects all other SDGs, such as improving human health and well-being (SDG3) by enhancing water quality and quantity, bolstering food safety and nutrition and energy security; advancing economic development (SDG8) through using food system residues to generate bioenergy, treating polluted water using the bioenergy and using treated water to grow food; and mitigating climate change (SDG13) through increasing resource efficiency and reducing CO_2 emissions. As nexus frameworks can make direct or indirect relationships with and between SDGs clear, they can enable integrated SDG implementation as requested in the Agenda 2030. Accordingly, nexus approaches can also monitor progress towards integrated SDG implementation. (Liu et al. 2018, p. 471)

Liu et al. (2018) point out that more research is needed to map the synergies between water, energy, and food and the SDGs:

> No quantitative nexus studies have linked with specific SDGs. (Liu et al. 2018, p. 469)

However, Hoff et al. (2019) have discussed the links between the Water-Energy-Food nexus and the SDGs further. They present 5 case studies of nexus implementations from Jordan, Lebanon, and Morocco. For each of these cases, they present qualitative scores of the fulfillment of relevant SDGs.

Evolution of the nexus approach

The word "nexus" originates from the Latin word "nectare" which means "to connect" (De Laurentiis et al. 2016, p. 3). A "nexus" has been defined as "one or more connections linking two or more things" (Yuan and Lo 2021, p. 1; Leck et al. 2015, p. 445). Nexus thinking in the realm of natural resource governance "is characterized as identifying the linkages across key natural resource sectors and careful planning of natural resource management strategy to improve their efficiency" (Yuan and Lo 2021, p. 1). The Food-Energy-Water nexus approach was initially introduced in the natural resource realm in 1983 to manage the challenges of resource scarcity (Scott et al. 2015). The nexus concept received relatively limited attention until 2010 when the scholarly literature focusing on the nexus expanded significantly. The development of the Food-Energy-Water nexus approach reached a landmark when the approach was advocated in the background paper

"Understanding the Nexus" (Hoff 2011) for the Bonn 2011 Nexus conference, which was arranged to prepare for the Rio+20/United Nations conference for sustainable development, and by the World Economic Forum 2011 report *Water Security: The Water-Food-Energy-Climate Nexus* (World Economic Forum 2011). The Food and Agriculture Organization of the United Nations (FAO) developed a Food-Energy-Water nexus approach and documented its applications through case studies in African countries, India, the Canarian Islands, and China (Food and Agriculture Organization of the United Nations 2014a).

The relationship between the water-energy-food nexus approach and the Sustainable Development Goals

Hoff et al. (2019) connect the nexus and sustainable development policy, describing the nexus as "a cross-sectoral and multi-level approach to deal with complex sustainability challenges" (Hoff et al. 2019, p. 3). Lazaro et al. (2022) concur: "The WEF nexus is a cross-cutting approach that through an interactive process can guide sustainable pathways to resource security and achieve the SDGs" (Lazaro et al. 2022, p. 6). More specifically, a "nexus approach can support a transition to sustainability, by reducing trade-offs and generating additional benefits" (Hoff 2011, p. 5). Hoff's advocacy of the approach in 2011 was motivated by a need to create food, energy, and water resource security in a context of increasing resource insecurity accelerated by the combined effects of climate change, increased population, urbanization, and changed diet and consumer habits (Hoff 2011; World Economic Forum 2011; Food and Agriculture Organization of the United Nations 2014b; International Renewable Energy Agency 2015; Segovia-Hernández et al. 2023; Unesco World Water Assessment Programme 2023). Hoff (2011) also takes the motivation for introducing the nexus to be a need to distance oneself from the practice of managing interconnected sustainability challenges separately: "Conventional policy- and decision-making in "silos" (…) needs to give way to an approach that reduces trade-offs and builds synergies across sectors— a nexus approach" (Hoff 2011, p. 7). Hoff repeatedly emphasizes the need for a holistic approach to resource governance: "Based on a better understanding of the interdependence of water, energy and climate policy, this new approach identifies mutually beneficial responses and provides an informed and transparent framework for determining trade-offs and synergies that meet demand without compromising sustainability" (Hoff 2011, p. 13). The nexus approach could contribute to decoupling economic growth from environmental degradation, in line with the United Nations' recommendation in the *Human Development Report 2020* (United Nations 2020). The development of the nexus approach in the scholarly literature has shifted focus since its introduction. According to a recent comprehensive literature review (Lazaro et al. 2022), five trends can be identified in the nexus literature: Between 2012 and 2016, the debate focused mainly on water management and natural resource security. Between 2017 and 2018, the debate focused mainly on linkages between the nexus, the Sustainable Development Goals, and the green economy. In 2019 the debate focused mainly on WEF nexus governance and policy integration. In 2020 the debate focused mainly on the "application of the nexus concept on

different scales, including regions, countries, watersheds, urban areas as well as other components coupled to the WEF nexus" (Lazaro et al. 2022, p. 1) and in 2021 the debate focused mainly on climate change and urban nexus challenges (Lazaro et al. 2022).

The relationship between the Sustainable Development Goals, human rights, and the capability approach

The Water-Energy-Food nexus approach was advocated as a tool to reduce tradeoffs and increase synergies between the Sustainable Development Goals. This section explicates the 17 Sustainable Development Goals (SDGs) introduced in the *Sustainable Development Agenda 2030*. It then discusses the relationship between the SDGs, human rights, and the capability approach, an influential account of wellbeing. The next section discusses how the nexus approach can contribute to reducing tradeoffs and increasing synergies between the goals. The nexus approach is aligned with a version of the capability approach that identifies characteristically human ways of functioning that, if nourished or neglected, can positively or adversely affect other characteristically human ways of functioning.

The Sustainable Development Goals

The 17 Sustainable Development Goals are:

> Goal 1. End poverty in all its forms everywhere. (United Nations 2015, p. 18)
>
> Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture. (United Nations 2015, p. 18)
>
> Goal 3. Ensure healthy lives and promote well-being for all at all ages. (United Nations 2015, p. 18)
>
> Goal 4. Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. (United Nations 2015, p. 18)
>
> Goal 5. Achieve gender equality and empower all women and girls. (United Nations 2015, p. 18)
>
> Goal 6. Ensure availability and sustainable management of water and sanitation for all. (United Nations 2015, p. 18)
>
> Goal 7 Ensure access to affordable, reliable, sustainable and modern energy for all. (United Nations 2015, p. 18)
>
> Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. (United Nations 2015, p. 18)
>
> Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. (United Nations 2015, p. 18)

> Goal 10. Reduce inequality within and among countries. (United Nations 2015, p. 18)
>
> Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable. (United Nations 2015, p. 18)
>
> Goal 12. Ensure sustainable consumption and production patterns. (United Nations 2015, p. 18)
>
> Goal 13. Take urgent action to combat climate change and its impacts. (United Nations 2015, p. 18)
>
> Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development. (United Nations 2015, p. 18)
>
> Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. (United Nations 2015, p. 18)
>
> Goal 16. Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. (United Nations 2015, p. 18)
>
> Goal 17. Strengthen the means of implementation and revitalize the Global Partnership for Sustainable Development. (United Nations 2015, p. 18)

There are numerous unresolved questions concerning the meaning and historical development of the concept of "sustainable development," and the implications of the answers to these questions for human development policy.

The following review draws on analyses in the literature of the concepts of "sustainable development" and "the Sustainable Development Goals" (Mensah 2019; Mazza 2021). These analyses answer the call to provide "more concise information on [the concept of sustainable development's] meaning, evolution, associated key concepts, dimension, the relationships among the dimensions, the principles, and their implications for global, national and individual actions in the quest for [sustainable development]" (Mensah 2019, p. 2).

I will first review the literature that analyzes the terms "human development," "sustainability," "sustainable development," and "the Sustainable Development Goals."

The term "human development" has been characterized in numerous ways. Representative characterizations include a process where "the human capacity increases in terms of initiating new structures, coping with problems, adapting to continuous change, and striving purposefully and creatively to attain new goals" (Peet 1999, p. 77; Du Pisani 2006, p. 88), and "that involves major changes in social structures, attitudes, and institutions, as well as economic growth, reduction of inequality, and eradication of absolute poverty" (Mensah 2019, p. 4; Todaro and Smith 2006).

The term "sustainability" has also been characterized in numerous ways. Representative examples include: "a capacity to maintain some entity, outcome or process over time" (Mensah 2019, p. 5; Basiago 1999). More specifically,

"sustaining a healthy economic, ecological and social system for human development" (Mensah 2019, p. 5; Milne and Gray 2013; Tjarve and Zemīte 2016; Mensah and Enu-Kwesi 2018; Thomas 2015), and "sustainability brings into focus human activities and their ability to satisfy human needs and wants without depleting or exhausting the productive resources at their disposal" (Mensah 2019, p. 5; Thomas 2015). Mensah and Enu-Kwesi (2018) argue that the characterization of "sustainability" should emphasize the importance of "cross-generational equity."

The term "sustainable development" has been described as "Development that can be continued either indefinitely or for the given time period" (Mensah 2019, p.6; Dernbach 1998, 2003; Lele 1991; Stoddart et al. 2011). The "Development paradigm" has evolved through numerous milestones: The concept was launched in Stockholm in 1972 at the UN Conference on the Human Environment. The conference resulted in the establishment of the UN Environment Program. The next milestone occurred in a pivotal report by Brundtland et al. (1987). The Brundtland Report "Our Common Future" formulated the most cited definition of "Sustainable Development:" "Development that meets the needs of the current generation without compromising the ability of future generations to meet their own needs" (Brundtland et al. 1987). Mensah (2019) points out: "Central to the Brundtland Commission Report were two key issues: the concept of needs, in particular the essential needs of the world's poor (to which overriding priority should be given); and the idea of limitations imposed by the state of technology and social organisation on the environment's ability to meet present and future needs" (Mensah 2019, p. 7; Kates et al. 2001). The report linked environmental protection economic development and social well-being for the first time (Mazza 2021). The recommendations of the report were followed up at the conference Rio Earth Summit 1992/the United Nations Conference on Environment and Development (UNCED). The implementation of the output of the Rio Earth Summit was followed up at the Rio+10/World Summit on Development in 2002. Three "Pillars of Sustainable Development" can be identified: 1. "Economic sustainability:" requires decision-making that is "fiscally sound" while taking into consideration "other aspects of sustainability" (Mensah 2019, p. 9; Zhai and Chang 2019). 2. "Social sustainability:" comprises "notions of equity, empowerment, accessibility, participation, cultural identity and institutional stability" (Mensah 2019, p. 9; Daly 1992). Mensah suggests that "'social sustainability' relates to the nexus between social conditions such as poverty and environmental destruction" (Mensah 2019, p. 9; Farazmand 2016). 3. "Environmental sustainability:" requires that "natural resources must be harvested no faster than they can be regenerated while waste must be emitted no faster than they can be assimilated by the environment" (Mensah 2019, p. 10; Diesendorf 2000; Evers 2018). The first effort to operationalize global sustainable development was the introduction of The Millennium Development Goals 2000. Approaching 2015, the goals were still not fully reached, and sequels to the goals were called for. These goals' sequels were developed at the Rio+20 2012/Rio Earth Summit, the United Nations Conference on Sustainable Development (UNCSD). The conference outcome document which was entitled "The Future We Want" included a process for

developing the sequels to the Millenium Development Goals, The Sustainable Development Goals. The Sustainable Development Goals as published in The Agenda 2030 have five main themes: "people," "planet," "prosperity," "peace" and "partnerships," which "span across the 17 Sustainable Development Goals" (Mensah 2019; Mazza 2021).

Allen et al. (2018) note that policymakers need to simultaneously implement the SDGs in a coherent and integrated way (Allen et al. 2018, p. 3).

They point out gaps regarding implementation that relate to "assessment of interlinkages" and "policy evaluation" (Allen et al. 2018, p. 16).

They point out that the limitations regarding application are obstacles to the implementation of the SDGs (Allen et al. 2018, p. 20).

Allen et al. (2016) identify scenario analysis and quantitative modeling as significant tools for sustainable development planning (Allen et al. 2016, p. 1).

They note that a single model probably will be unable to analyze all of the SDG targets (Allen et al. 2016, p. 1).

They suggest that "scenario analysis and modeling has emerged as a method that is particularly well suited to the task of taking a long-term view and attempting to harmonize socioeconomic and environmentalist goals" (Allen et al. 2016, p. 3).

Allen et al. (2016) point out the need for more research on the strengths and weaknesses of models and model approaches (Allen et al. 2016). They suggest that "bottom-up approaches can assist in detailed technological assessment and meaningful evaluation of alternatives at the sectoral level" (Allen et al. 2016, p. 4).

They elaborate on the suitability of bottom-up approaches as tools for planning on the sectoral level, suggesting that these approaches have "more limited scope and detailed coverage of technologies and alternatives …" (Allen et al. 2016, p. 4).

They note "the absence of unique modeling approaches and model types that will address all analytical requirements underpinned by the new SDGs" (Allen et al. 2016, p. 4). They emphasize that the choice of the model must be guided by what we intend to measure using the model: "Rightly Nicholson (2007) points out the lack of a single universal methodology suited to all problems; with the utility of modelling approaches dependent on the nature of the system of focus, and the type of prediction desired" (Allen et al. 2016, p. 4).

Calvin and Bond-Lamberty (2018) conducted a comprehensive review of the so-called Integrated Assessment Models. Amongst these, the so-called Integrated human-earth models are of particular relevance for the assessment of synergies and tradeoffs between the SDGs: "Integrated human-earth models are designed to explore and answer questions related to possible feedbacks between human and natural systems" (Calvin and Bond-Lamberty 2018, p. 2). Moreno et al. (2023) hold that research regarding "SDG interactions with mitigation scenarios … is a novel area of research" (Moreno et al. 2023, p. 2). Nerini et al. (2017) discussed interactions between the goal that covers clean energy and the rest of the SDGs. Müller et al. (2015) explore interactions between SDGs at a "landscape level," which provides "a local scale and integrates an understanding of biophysical resource systems as well as the socio-economic context" (Müller et al. 2015, p. 50). In summary, there is a significant need for research on synergies and tradeoffs between the SDGs at a subnational, and local sector level.

The place of human rights within the Sustainable Development Goals

According to the *Sustainable Development Agenda 2030*, the 17 goals comprise "a plan of action" for human development. The goals are grounded in *The Declaration of Human Rights* (United Nations 2015, p. 4). *The Human Development Report* of 2016 describes human rights as the "bedrock" of human development (United Nations 2016, p. 85). The following quotes comprise all the *explicit* references to human rights in the SDGs. Citing all the references to human rights in the SDGs is helpful to provide a complete picture of the occurrence of human rights in the SDGs, and to probe into the function of human rights in the SDGs. The remainder of this section draws on (Andersson 2024) These are all the explicit mentions of human rights in the SDGs:

1. The SDGs aim to "realize the human rights of all," (United Nations 2015, p. 1) and "to protect human rights" (United Nations 2015, p. 3).
2. The agenda commits itself "to respect, protect and promote human rights and fundamental freedoms for all" (United Nations 2015, p. 6).
3. "It is grounded in the Universal Declaration of Human Rights, international human rights treaties" (United Nations 2015, p. 4).
4. The agenda recognizes a "universal respect for human rights and human dignity" (United Nations 2015, p. 4).
5. The agenda will "strive to provide children and youth with a nurturing environment for the full realization of their rights and capabilities" (United Nations 2015, p. 7).
6. It claims to pursue a "human right to safe drinking water" (United Nations 2015, p. 3).
7. "The new Agenda recognizes the need to build peaceful, just and inclusive societies that provide equal access to justice and that are based on respect for human rights (including the right to development)" (United Nations 2015, p. 9).

Three main interpretations of what role human rights play in the SDGs carry textual support: Human rights and the SDGs are progressive, aspirational goals or benchmarks to strive for. 2. Human rights are the moral grounding of the SDGs. 3. The SDGs are a call for implementation of human rights. Reference 1 states that the SDGs will "realize" and "protect" human rights. These formulations support interpretation 3: The SDGs are *a call for implementation* of human rights. Reference 2 also states that the SDGs will "protect" human rights, and thereby supports interpretation three. Reference 3 describes the SDGs as "grounded" in human rights. This formulation supports interpretation 2: Human rights are the *moral grounding* of the SDGs. Reference 4 states that the SDGs recognize "a universal respect for human rights." This claim is compatible with all interpretations. Reference 5 states that the SDGs will "realize" children's rights. It supports interpretation three, as does reference six which states that the SDGs will protect the alleged human right to safe drinking water. Reference 7 describes the SDGs as "based" on human rights. This formulation supports interpretation two. It is important to note that, although interpretations 2 and 3 carry more textual support than interpretation 1, all these interpretations are compatible with each other. It is also important to note that

although the SDGs could be interpreted as a call for implementation of Human Rights, the United Nations has no legal authority to *enforce* such implementation.

So, the SDGs are related to human rights in either or all these ways. But despite the prolific use of the concept of "a right," scholars disagree regarding the adequacy constraints of a plausible definition of "a right." The United Nations adopts one influential interpretation, stating that human rights are entitlements, "claims." These claims correlate to the duties of agents and institutions to provide certain resources, and services, or to abstain from engaging in certain behaviour. The United Nations *Human Development Reports* of 2002 and 2016 explicitly interpret human rights as claim rights. The *Human Development Report* of 2016 states: "To have a particular right is to have a claim on other people or institutions that they should help or collaborate in ensuring access to some freedom" (United Nations 2016, p. 86). The people or institutions towards whom these claims are held are "duty holders." "Duty holders support and enhance human development and are accountable for a social system's failures to deliver human development" (United Nations 2016, p. 8). Human rights then provide legitimacy to the SDGs.

The relationship between human rights and the capability approach

According to the United Nations, human rights are grounded in the so-called capability approach. The capability approach provides an account of quality of life that has brought a paradigm shift to the realm of development economics. The capability approach offered a new tool to measure different countries' levels of human development. The United Nations explicitly describes the relationship between human rights and capabilities: "The best way to secure human rights may be to consider rights in terms of capabilities. The right to bodily integrity, to associate freely, to political participation and all other rights are secured when the relevant capabilities are available. To secure a right is to enable people to be or do something that they have reason to value" (United Nations 2016, pp. 25, 86). Amartya Sen pioneered the capability approach in the 1979 Tanner Lectures and his pivotal article "Equality of What?" (Sen 1980). Sen's version of the capability approach takes the quality of life or well-being to be a real opportunity to exercise capabilities. According to Sen, capabilities are the combinations of functionings that a person can achieve (Sen 1985b, p. 198). According to Sen, functionings are all the valuable things that a person may "do" or "be" (Sen 1985b). Sen holds functionings to be "any state of existence" of a person (Sen 1985a, p. 10). Examples of valuable "doings" include engaging in social activities, working, and participating in political activities. Examples of valuable "beings" include being healthy, physically unimpaired, and educated at a certain level. Sen puts more emphasis on the value of freedom to achieve functionings than on the value of the functionings themselves (Sen 1990, p. 52). He acknowledges, however, that the value of the functionings is intrinsic and affects the level of the freedom to achieve the functionings. According to Sen, positive freedom is the capability to achieve different combinations of functionings. Sen's outcome-oriented rights theory views rights as expressing "ethical demands" (Sen 2004, p. 319). These rights are goals that

correlate to both positive obligations to provide resources and assistance and negative obligations to abstain from interfering with human beings in certain ways. These obligations belong to anyone who reasonably stands in a position to fulfill such obligations (Sen 2004, p. 319). He recognizes that some functionings and capabilities are more "basic" than others in the sense that people are seriously deprived if they are denied access to these functionings and capabilities (Sen 1984, p. 320). He holds that people have "basic" rights to these basic functionings and capabilities. One motivation for introducing the capability approach was dissatisfaction with accounts of quality of life that measure quality of life in terms of people's perception of their quality of life, their share of certain resources, or their Gross Domestic Product. Measuring quality of life in terms of perceived well-being is problematic because of so-called adaptive preferences: people who have adapted their aspirations to their low expectations regarding their physical and mental health may *regard* themselves as healthy. Measuring quality of life in terms of Gross Domestic Product is problematic both because this measure says nothing about the distribution of wealth within a population, and because wealth does not necessarily bring the quality of life in a plausible sense of the term. Measuring quality of life in terms of people's share of certain resources is also problematic because different persons differ regarding their ability to convert resources into capabilities. For instance, physically disabled or seriously ill individuals may need to spend a large proportion of their income on equipment to aid their mobility, or on healthcare. According to Sen, the best space of comparison regarding countries' achieved equality is capabilities. The answer to the question "equality of what?" is hence "equality of capability." While Sen has provided an account of the relationship between rights and capabilities, Martha Nussbaum identifies a need to elaborate on the relationship further. Nussbaum stated already in 1997, and again in 2003, that the relationship between rights and capabilities "remains yet unexplored" and that the conceptual relationship between the capabilities approach and rights "needs further scrutiny" (Nussbaum 1997, p. 278; 2003, p. 37). An important aspect of her capabilities approach is to "illuminate some of the issues that must be faced when one does attempt to connect the two ideas" (Nussbaum 1997, p. 279). These issues include disagreements regarding the logical structure, content, and function of rights, as well as controversies regarding the demarcation of the class of rights bearers. Nussbaum holds that users of the rights concept need to "link their references to a theory that answers at least some of these questions" (Nussbaum 1997, p. 279). She holds that "the language of capabilities gives important precision and supplementation to the language of rights" (Nussbaum 2003, p. 37). She stated already in 1997 that because of the need to develop such a theory, "a different language has begun to take hold in talk about people's basic entitlements. This is the language of capabilities and human functioning" (Nussbaum 1997, p. 275). According to Nussbaum, we need to combine the capabilities approach with an account of rights because "rights language reminds us that people have justified and urgent claims to certain types of urgent treatment" (Nussbaum 1997, p. 295). The concept of a right is closely connected with the concept of a capability because to secure a right *is* to put someone "in a position of capability" (Nussbaum 1997, p. 295). Nussbaum characterizes rights as involving "an especially urgent and

justified claim that a person has, simply by being a human adult" (Nussbaum 1997, p. 293). And: "To secure a right to a citizen … is to put them in a position of capability to go ahead with choosing that function if they should so desire" (Nussbaum 1997, p. 293). The core connection between human rights and basic capabilities is that "just by virtue of being human, a person has a justified claim to have the capability secured to her; so that a right in that sense would be prior to capability, and a ground for securing a capability" (Nussbaum 1997, p. 293). She holds that the capability approach can help us "understand that what is involved in securing a right" which "is usually a lot more than simply putting it down on paper" (Nussbaum 1997, p. 293). Hence, the reference to capabilities indicates that respect for rights requires that people have actual access to the capability sets that are prerequisites for leading a dignified life. In addition, combining human rights with a capability approach communicates the moral importance of the opportunity to exercise agency: to be autonomous (Nussbaum 2003, p. 40). Combining rights with the capability approach also allows a theory of human rights to accommodate positive rights to rights protection (Nussbaum 2003, p. 39). Insisting that the function of rights is to protect capabilities, that is, opportunities to choose functionings, respects pluralism of comprehensive views regarding what characterizes a good life (Nussbaum 2003, p. 43). Combining human rights with Nussbaum's capability approach also allows a human rights theory to accommodate the rights of humans with mere potential for developing a capacity to choose functionings. Her capability approach holds that such beings should be provided the resources and support required to develop such a capacity (Nussbaum 2003, p. 50). Additional benefits are: Her capability approach is particularly suited to detect inequalities between men and women in the realm of family life. This is because the asymmetric distribution of domestic responsibilities between men and women affects women's opportunities to access certain capabilities. Also, the idea that the function of rights is to protect capabilities is not tied to any cultural tradition (Nussbaum 2003, p. 39). Her recent (2011) capability approach defends a list of ten central capabilities that must be made available to every person as a matter of justice. Access to the central human capabilities is, according to Nussbaum, necessary to lead a "fully human" life and to live in "dignity." The central human capabilities are interpretations of what she takes to be a global consensus regarding what characterizes a dignified human life. Nussbaum argues that these capabilities should provide the moral basis of constitutional rights that protect capabilities. She holds that the list can be accepted as a "module" along with people's diverse comprehensive views regarding what characterizes a good life. She holds that there is a broad global consensus regarding the contents of the list. The ten central human capabilities must, however, be specified through public reasoning. She endorses the method of reflective equilibrium, which identifies stable moral intuitions regarding what is required to live a dignified human life and then attempts to fit these intuitions with general moral principles. These moral principles should then be interpreted through a process of public deliberation amongst "reasonable" advocates of different comprehensive doctrines. The purpose of such deliberation is to reach an overlapping consensus between these comprehensive doctrines. Sen is willing to accept such a list if it is constructed for a specific purpose and is open to revision through public

deliberation (Sen 1980). Sen's and Nussbaum's capability approaches concur in important aspects. Both agree that the capability approach is committed to the claim that we should treat each person "as an end in themselves" in the sense that the well-being of everyone, rather than the aggregation of a group of individuals' well-being, is of moral importance. The capability approach is also committed to the pluralism of values because the capability achievements differ in quality and "cannot without distortion be reduced to a single numerical scale" (Nussbaum 2011, p. 19). This communicates dissatisfaction with the measurement of quality of life in terms of GDP, or aggregated utility. An important challenge of Nussbaum's list of central human capabilities is to address the potential tension between the list viewed as a set of objectively correct moral principles supported by moral reflection, and the freedom of individual societies to specify the relatively abstract principles through public deliberation between "reasonable" citizens. The problem is that "a commitment to objectivity seems difficult to reconcile with the way the [capability approach] legitimates public reason, i.e., without criteria to ascertain whether public reason is correct" (Domselaar 2009, p. 190). The challenge of formulating a plausible account of the "objectivity" of public reason has been extensively discussed, and the task of meeting this challenge has been identified as crucial to developing the capability approach (Larmore 1989, 1999; Rawls 1993; Nussbaum 2001). There is, however, no consensus regarding this issue. A second challenge is the indeterminacy of public reasoning. Nussbaum's capability approach holds that public reason should determine what minimum level of capabilities every human being should have access to. She calls this "the adequate threshold level." She grants considerable space of deliberation for each state to interpret what the adequate threshold level should be. Her unwillingness to impose any specific normative view regarding what the adequate threshold should be brings the drawback of allowing for a significant lack of guidance in local settings.

Conflicts between the Sustainable Development Goals

The discussion of the contemporary debate on the relationship between the Sustainable Development Goals, human rights, and the capability approach identified several challenges: 1. possible tensions between the list of central human capabilities interpreted as a set of moral principles and the justification of public reason, and 2. challenges related to the indeterminacy of the threshold for the ten central capabilities when these are implemented in local settings. We now address related challenges involving conflicts between the Sustainable Development Goals. The Sustainable Development Goals 2, 6, and 7 explicitly state that everyone should have access to water and sanitation, clean and affordable energy, and food security. The goals are integrated and interdependent. Nevertheless, due to the increasing scarcity of the resources needed to realize the goals, which has accelerated partly due to climate change, population increase, urbanization, and changing consumer habits and diets, practical conflicts requiring trade-offs between the goals are inevitable. Water and sanitation, clean and affordable energy, and food security are examples of some of the most crucial and scarce resources needed to achieve the realization of the goals. The Intergovernmental Panel on Climate Change

(IPCC) published the special report *Global Warming of 1.5 °C* in October of 2018. The report presents projections of possible climate scenarios. One of the main messages of the report is that no climate projection that predicts the limitation of global warming to 1.5 °C above pre-industrial levels can accommodate all the Sustainable Development Goals (SDGs): "To date, no pathway in the literature proves to achieve all the SDGs because several targets are not met or not sufficiently covered in the analysis, hence resulting in a sustainability gap" (Intergovernmental panel on climate change 2018, p. 467). The United Nations identifies a knowledge gap regarding research aimed at meeting this challenge in specific contexts: "Limited literature has systematically evaluated context-specific synergies and trade-offs between and across adaptation and mitigation response measures in 1.5 °C compatible pathways and in the SDGs" (Intergovernmental panel on climate change 2018, p. 476).

Jonathan Wolff and Avner De-Shalit, in their influential book *Disadvantage* (2007) introduce a novel version of the capability approach that can be applied to reduce tradeoffs and strengthen synergies between the SDGs. Their version of the capability approach supports an order of priority between human functionings. They argue that scarce resources should be directed towards preventing deficits of capability protection that cause additional deficits of capability protection. They label such deficits "corrosive disadvantages." They also suggest that scarce resources should be directed towards protecting capabilities that, if protected, contribute to the protection of other capabilities. Such protections promote "fertile functionings" (Wolff and De-Shalit 2007). Undernourishment and insufficient access to water, sanitation, and clean and affordable energy arguably cause corrosive disadvantages. Such deprivations adversely affect virtually all other capabilities, and the protection of sources of nourishment, water, and clean affordable energy. Limitations of the impacts of climate change arguably protect fertile functionings. It is important to note that their version of the capability approach, like Sen's and Nussbaum's, emphasizes every human being's entitlement to capability security. Their account deems unacceptable maximization of capability security at the expense of some human beings. A normative implication of their characterization of disadvantage is that we should prevent some human beings from facing larger "clusters" of disadvantages compared to others. A human being suffers from a greater cluster of disadvantages if she has access to a significantly smaller set of capabilities compared to others. They also emphasize the importance of people's *secure* access to capabilities. Although a person might have access to a set of capabilities, the access might be insecure if she cannot rely on continued access to these capabilities.

Creating synergies and reducing tradeoffs

This section outlines how the Food-Energy-Water nexus approach, in alignment with Wolff's and De-Shalit's version of the capability approach, could reduce tradeoffs and increase synergies between the Sustainable Development Goals. We saw that the SDGs are grounded in human rights and that the function of human rights is to protect capabilities. Hence, to reduce conflicts between the capabilities-based human rights that correlate to the SDGs *is* to reduce conflicts between the

SDGs. The following discussion focuses on the goals that mention food security, clean affordable energy, water, and sanitation. All the goals are connected, and no single goal can be fully realized in isolation. One cannot compensate for failure to meet one goal to a sufficient degree by meeting another goal to a greater degree. We saw that the United Nations emphasizes that increasing resource scarcity accelerated by climate change necessitates a shift from "siloed" to integrated thinking. The resources of water, energy, and food are interconnected. For instance, energy is necessary to pump and manage water, water is used to produce energy, and water and energy are essential for food production. Increased demand for energy contributes to global warming due to the release of carbon dioxide from fossil-based energy sources. Hence, a transition to renewable energy is required to satisfy the growing energy demand while mitigating climate change. The development of renewable energy sources such as terrestrial-based biofuels can, however, compete with the cultivation of food crops and be very water-consuming. Meeting the increasing need to feed a growing population will require increased mechanization, fertilization, and irrigation (Hoff 2011). Water is commonly regarded as a cross-section issue in the nexus literature and has been identified as a key resource in the early nexus literature (Hoff 2011). Integrated resource governance could reduce some of these trade-offs, by introducing, for instance, biomass cultivation in wastewater that reduces the competition with production of food crops and the use of clean water. However, geographical and social circumstances, as well as a choice of species for biomass cultivation might affect the overall success of the realization of the Sustainable Development Goals. Integrated resource governance could increase synergies and reduce tradeoffs between the Sustainable Development Goals 2, 6, and 7, thereby supporting fertile "functionings" and reducing corrosive disadvantage caused by deprivation of food, energy, and water. The following section elaborates on how integrated resource governance could be implemented within the aquaculture industry in an Arctic context.

Implementation of a water-energy-food nexus to the Arctic context and local university-industry collaboration

This section outlines an influential implementation model for the Water-Food-Energy nexus approach and the model's alignment with Wolff's and De-Shalit's version of the capability approach. It then discusses what steps would be required to implement the model within the aquaculture industry in an Arctic context. Specifically, it discusses the potential implementation of the model in a collaborative carbon capture and utilization project involving UiT The Arctic University of Norway, and local ferrosilicon producer Finnfjord AS based in northern Norway.

Implementation models

The following four-step model for implementation of the Water-Energy-Food nexus approach in specific geographical and social contexts has been advanced in the scholarly literature by Terrapon-Pfaff et al. (2018):

Step 1: To understand the complex interlinkages between the governance of water, energy, and food, we need to produce a qualitative mapping of the links between the water, food, and energy subsystems in a specific geographic and social context (Terrapon-Pfaff et al. 2018, p. 412). The mapping should illustrate the influence different elements in the sub-system of the nexus have on each other (Terrapon-Pfaff et al. 2018, p. 412).

Step 2: To better understand the relevance, scale, and/or scope of the Water-Energy-Food Nexus links, we should quantify the links (Terrapon-Pfaff et al. 2018, p. 412) and their influence, strength, and strategic import should be investigated. This process should gather information to support the identification of the most critical links (Terrapon-Pfaff et al. 2018, p. 412).

Step 3: We should then identify critical links based on steps 1 and 2. A link is critical if it "[influences] the behavior of other elements of the system, are strong in terms of scope or scale, and or are of strategic importance because they can be influenced by actions and decisions" (Terrapon-Pfaff et al. 2018, p. 412).

Step 4: Finally, we should produce leverage of results. The results should be applied in practice in specific geographical and social contexts to generate synergies and avoid tradeoffs between the Sustainable Development Goals. The application should be site and technology-specific (Terrapon-Pfaff et al. 2018, p. 412).

Terrapon-Pfaff et al. (2018) and Taguta et al. (2022) emphasize that no existing model can account for all the complexities between the links in specific geographic and social contexts. "This highlights a gap for local-scale tools that can model, simulate and analyze local WEF nexus for assessing challenges, impacts, interventions and adaptation to change that can promote sustainable development at the grassroots level" (Taguta et al. 2022, p. 12; Terrapon-Pfaff et al. 2018). This gap has been emphasized by several contributors to the literature: "Preferably, WEF nexus tools should be robust, multiscalar, flexible and adaptable across users, uses, spatial scale and scope, only requiring new, specific location-adapted inputs and data" (Taguta et al. 2022, p. 14; International Renewable Energy Agency 2015). "Only 30% of the tools are applicable at local scales. In contrast, some tools are restricted in geographic scope and scale of application, for example, ANEMI 3 and WEF models for large and household scales, respectively" (Taguta et al. 2022, p. 1). Daher and Mohtar (2015) have developed a tool for the identification and quantification of the links between water, energy, and food in specific geographic contexts. Their tool is designed for quantifications of links at a national level, however. Nevertheless, their tool is relevant for quantifications of links for local businesses as a revised version of their tool might serve that purpose. WEF Nexus Tool 2.0 allows users such as decision-makers/policymakers to feed parameters such as energy and water sources of their proposed course of action into the model, which calculates the water, energy, and land requirements, carbon footprint, costs, and other factors. The model provides "a generic, holistic framework that considers the existing interlinkages between the systems and offers decision/policymakers a solid foundation for debate, discussion and action" (Daher and Mohtar 2015, p. 750). Daher and Mohtar emphasize that "Explicit quantification of these relations is imperative for proper assessment of different scenario variations and guides the decision-making process" (Daher and Mohtar 2015, p. 753). The tool calculates the "Total water

requirement for the scenario"; "Total land requirement … based on local production and yields"; "Local energy requirement"; "Local carbon footprint"; "Financial cost"; "Energy consumed through import"; "Carbon emission through import" (Daher and Mohtar 2015, p. 756).

An implementation model for an Arctic carbon capture and utilization project

I will now outline what would be required to apply the model to the aquaculture industry in an Arctic setting. Specifically, I will discuss the application of the model to a carbon capture and utilization initiative developed in collaboration between UiT The Arctic University of Norway, and local ferrosilicon producer Finnfjord AS, located in northern Norway. The collaboration comprises a research project aimed at large-scale cultivation of microalgae to be included as a component of locally produced fish feed. The microalgae feed on carbon dioxide released by the factory fume, which is pumped into the silos holding the algae cultivation. The silos will, after upscaling of the cultivation facilities, hold a least 3,000,000 L. The project aims at making the production carbon neutral and sufficiently upscaled to produce affordable algae-based fish feed for the aquaculture industry. Industrial fishing has significantly depleted the fish stock of the oceans. A growing global demand for aquaculture products requires a growing aquaculture industry to meet the need. The use of soy and wild-caught fish as components of fish feed in the aquaculture industry is unsustainable. Major challenges facing aquaculture industries that aim at replacing soy and wild-caught fish-based feed with algae-based feed include technical challenges related to the upscaling of the production and challenges related to lights capable of penetrating algae-dense broth. The challenges also include competition with the agriculture industry for land areas required for cultivation facilities, and the use of water to cultivate algae. Upscaling to an industrial scale is essential to produce affordable products. It is important to note that the project mainly delays the release of carbon dioxide into the atmosphere, rather than removing it entirely from the carbon cycle. Currently, the project exemplifies a water-food nexus implementation. The project protects water and the atmosphere from the immediate release of carbon dioxide and utilizes the carbon dioxide for sustainable food production through the production of fish feed for the aquaculture industry. The project produces fish feed with high omega 3 content which benefits fish health and ensures that the final product is omega 3 rich. Hence, there are critical links between water and food resources. Assessment of the nexus' efficiency regarding the creation of synergies and reduction of tradeoffs between the SDGs would need to include assessment of factors such as transportation needs, land-area needs, water consumption, and whether the cultivation must be seasonal due to local weather conditions (Miara et al. 2014). Applying a revised version of the implementation model would require context-specific mapping and quantification of the links between food, water, and energy. It would then require the identification of critical links and leveraging of the results by the implementation model outlined above. Research output related to algae cultivation has already contributed quantifications of land, water, and energy requirements of the entire production process of algae cultivation, fish feed production, and local salmon farming.

The research team used the following methods to identify and quantify some links between aspects of water, energy, and food: In the process of quantifying the amount of CO_2, C, O2, energy, and minerals in the system they accumulated data by measuring or "by applying literature values" (Andersson et al. 2023, p. 6; Eilertsen et al. 2022, 2023). Parts of the process were performed by the instructions in ISO 14044 (Matthews et al. 2014). In addition, they referred to information about "the sustainability of algae cultivation, crop use in feed and salmon aquaculture from scholarly sources and industry reports" (Andersson et al. 2023, p. 6; Boyd 2015; Gjøsund et al. 2020; Hognes et al. 2011; Rotabakk et al. 2020; Eilertsen et al. 2022, 2023). They documented the following results: Uptake of CO_2 from the fume added to the culture was between 35% and 34%. An important consideration is that the production of microalgae feeds results in the production of 1.2 kg O2 per kg salmon produced. On the other hand, cultivation of algae that needs surplus LED illumination results in an energy use that is approximately 50 MJ kg^{-1} higher than production of traditional feed. (Eilertsen et al. 2022, 2023; Andersson et al. 2023) The following potential environmental gains from using 50% algae in salmon feed at Flaktstavåg laks AS, provided CO_2 capture at the algae cultivation facility at Finnfjord AS have been documented in (Eilertsen et al. 2022):

1. CO_2 reduced emission to air—Finnfjord AS 11,000 tons/year (Eilertsen et al. 2022).
2. CO_2 footprint reduction in salmon production—Flakstavåg laks AS 13,000 tons/year (Eilertsen et al. 2022).
3. Reduction in NOx outlet to air—Finnfjord AS 28 tons/year (Eilertsen et al. 2022).
4. Increased O2 emission to air/sea—Finnfjord AS 11,000 tons/year (Eilertsen et al. 2022).

Implementation of the nexus approach strengthens fertile functionings and reduces corrosive disadvantages. Fertile functionings depend on access to food, energy, and water. Lack of access to these resources creates corrosive disadvantages: without access to food, energy, and water, human beings are denied access to all other capabilities. By focusing on strengthening critical links between food, energy, and water, we can strengthen the realization of fertile functionings and reduce corrosive disadvantages. Strengthening critical links between water energy and food contributes to breaking up clusters of corrosive disadvantages and strengthening fertile functionings for people in specific geographical and social contexts. It also contributes to creating capability security of fertile functionings. Implementation of the water-energy-food nexus approach is an example of the implementation of Wolff's and De-Shalit's version of the capability approach. Accomplishing such implementation would require cross-disciplinary collaboration between the natural sciences, social sciences, and the humanities. Successful implementation of this task would fill a significant research gap identified by the United Nations, the European Commission, and the Nexus literature. While important, recent research contributes to this pursuit in the context of the MENA regions (Miara et al. 2014), applications of the nexus approach in the Arctic are lacking.

The application of the nexus approach to algae cultivation has been investigated, but the research findings have not yet been applied to an Arctic setting.

Combinations of algae-based fish feed production and algae-based biofuel production could bring additional benefits to both industries. Expansion of the project to include algae-based biofuel could contribute to reducing costs for both the aquaculture industry and biofuel production.

Discussion and implications

Results

The key results are 1. mappings and quantifications of carbon footprints of carbon capture and utilization through a university-industry collaboration in an Arctic context. 2. Quantifications of achievements of SDG indicators. 3. Development of a conceptual framework that analyses the conceptual relationships between the water-energy-food nexus, SDGs, human rights, and the capability approach. The interpretations of the results are that there are potentially more efficient methods for quantification of synergies and tradeoffs between the SDG indicators in a local context, and to use this information to increase synergies and reduce tradeoffs between the SDG indicators. The results imply that the results provide enhanced methods for operationalization of the SDGs in a local context.

The study presented in this article has important policy implications. Bazilian et al. (2013) note that "Few approaches have comprehensively addressed the broader interdependencies" (Bazilian et al. 2013, p. 158) within the nexus. Miara et al. (2014) describe "policy goals as drivers of algal system design" (Miara et al. 2014, p. 201). Nevertheless, Bazilian et al. (2013) note that "there is little work focusing on how to support decision making at the nexus" (Bazilian et al. 2013, p. 158).

They note that "the approach to the energy-water-food nexus normally depends on the perspective of the policy maker, which might provide some context for how to view system optimization" (Bazilian et al. 2013, p. 158). They outline how such optimization might be realized: "Ideally, multi-stakeholder, multiple optimization analysis with sensitivities on boundary conditions and scenario design will lead to system design that address key stakeholder priorities" (Bazilian et al. 2013, p. 158). However, stakeholders' priorities might conflict, and an adjudication method is necessary. A focus on the optimization of fertile functionings and reduction of corrosive disadvantages could guide stakeholders' priority setting. The term "co-product" implies assumptions about stakeholders' understanding of what an "optimal" output of a system is. The system outputs of algae cultivation can be "optimized" toward different "primary products:" "food output," "carbon sequestration," and "waste treatment" (Bazilian et al. 2013, p. 161). Agwu et al. (2022) explore a stakeholder theory perspective and apply it to the algae cultivation project discussed in this article. Agwu et al. (2022) discuss how to engage stakeholders around a common purpose by creating a shared value framework. Agwu et al. (2022) note that "little is known about

stakeholders' motivations to participate in creating shared value and how sustainable value is created" (Agwu et al. 2022, p. 3). Optimizing fertile functionings and reducing corrosive disadvantage could be principles that could guide such a definition of "shared value."

Conclusions

This article discussed a context-specific application of a four-step implementation model for the Water-Energy-Food nexus in the Arctic. The implementation model is aligned with a novel version of the capability approach that can guide resource prioritization through the identification of critical links between water, energy, and food, resources that support fertile functionings. Specifically, it advanced the first application of such a model to local university-industry carbon capture and utilization research collaboration in the Arctic. It then outlined how this research finding could be developed to fill a significant research gap in the nexus literature: to apply the extensively developed nexus theorizing to local industry in the Arctic. The limitations of the results are that the predictions of the impact of the project for SDG operationalization are still tentative due to the project being a pilot study. The recommendation for future research is that the suggested model should be systematically tested and adjusted in different geographic settings.

Funding Open access funding provided by UiT The Arctic University of Norway (incl University Hospital of North Norway).

Data availability The author confirms that all data generated or analysed during this study are included in this published article.

Code availability Not applicable.

Declarations

Research involving human participants and/or animals Not applicable. The research involved no human participants and/or animals.

Informed consent Not applicable.

Conflict of interest The author claims no conflict of interest.

References

Agwu UJ, Oftedal EM, Bertella G (2022) Why not use the sea? A shared value approach to sustainable value creation when using carbon dioxide as a valuable resource in manufacturing. Front Sustain 3(9):1–21

Allen C, Metternicht G, Wiedmann T (2018) Initial progress in implementing the Sustainable Development Goals (SDGs): a review of evidence from countries. Sustain Sci 13:1453–1467

Allen C, Metternicht G, Wiedmann T (2016) National pathways to the Sustainable Development Goals (SDGs): a comparative review of scenario modelling tools. Environ Sci Policy 66:199–207

Andersson A-KM, Stokke Ø, Agwu UJ, Strømsheim EW, Ingebrigtsen RA, Wintervoll GH, Aspen T, Eilertsen HC (2023) Mass cultivation of microalgae III: a philosophical and economic exploration of carbon capture and utilization. Sustainability 15(24):16826

Andersson A-KM (2024) Sustainable Development Goals, human rights, and the capability approach in an arctic context. In: Øyvind S, Oftedal EM (eds) Making CO_2 a resource the interplay between research, innovation and industry. Routledge

Basiago AD (1999) Economic, social, and environmental sustainability in development theory and urban planning practice. In: The environmentalist. Kluwer Academic Publishers, Boston

Bazilian M, Davis R, Pienkos P, Arent D (2013) The energy-water-food nexus through the lens of algal systems. Ind Biotechnol 9:158–162

Boyd CE (2015) Overview of aquaculture feeds: global impacts of ingredient use. In: Allen Davis D (ed) Woodhead Publishing series in food science, technology and nutrition, feed and feeding practices in aquaculture. Woodhead Publishing, pp 3–25

Brundtland GH, et al. (1987) Our common future: report of the world commission on environment and development. UN-Dokument A/42/427, Geneva

Calvin K, Bond-Lamberty B (2018) Integrated human-earth system modeling—state of the science and future directions. Environ Res Lett 13:063006

Daher BT, Mohtar RH (2015) Water–energy–food (WEF) Nexus Tool 2.0: guiding integrative resource planning and decision-making. Water Int 40(5):748–771

Daly HE (1992) U.N. conferences on environment and development: retrospect on Stockholm and prospects for Rio. Ecol Econ 5:9–14

De Laurentiis V, Hunt VD, Rogers DC (2016) Overcoming food security challenges within an energy/water/food nexus (EWFN) approach. Sustainability 8(1):95

Dernbach JC (1998) Sustainable development as a framework for national governance. Case West Reserve Law Rev 49(1):1–103

Dernbach JC (2003) Achieving sustainable development: the centrality and multiple facets of integrated decision making. Ind J Global Legal Stud 10:247–285

Diesendorf M (2000) Sustainability and sustainable development. In: Dunphy D, Benveniste J, Griffiths A, Sutton P (eds) Sustainability: the corporate challenge of the 21st century Sydney. Allen & Unwin

Domselaar IV (2009) Nussbaum's capabilities approach: in need of a moral epistemology? Rechtsfilosofie & Rechtstheoe 38(3):186–201

Du Pisani JA (2006) Sustainable development – historical roots of the concept. Environ Sci 3(2):83–96

Eilertsen HC, Eriksen GK, Bergum J-S, Strømholt J, Elvevoll E, Eilertsen K-E, Heimstad ES, Giæver IH, Israelsen L, Svenning JB, et al (2022) Mass cultivation of microalgae: I. experiences with vertical column airlift photobioreactors, diatoms and CO_2 sequestration. Appl Sci 12(6):3082

Eilertsen HC, Strømholt J, Bergum JS, Eriksen GK, Ingebrigtsen R (2023) Mass cultivation of microalgae: II. A large species pulsing blue light concept. BioTech 12(2):40

Evers BA (2018) Why adopt the Sustainable Development Goals? The case of multinationals in the Colombian coffee and extractive sector. Master Thesis, Erasmus University Rotterdam

European Commission (2016) The water-energy-food nexus: foresight for research and innovation in the context of climate change. https://op.europa.eu/en/publication-detail/-/publication/52d85c24-e1d6-11e5-8a50-01aa75ed71a1/language-en

Farazmand A (2016) Global encyclopedia of public administration, public policy, and governance. Springer International Publishing, Amsterdam

Food and Agriculture Organization of the United Nations (2014a) The state of food and agriculture: innovation in family farming. Available via The State of Food and Agriculture (SOFA) 2014 (fao.org)

Food and Agriculture Organization of the United Nations (2014b) Walking the nexus talk: assessing the water-energy-food nexus in the context of the sustainable energy for all initiative. Available via Walking the nexus talk: assessing the water-energy-food nexus in the context of the sustainable energy for all initiative (fao.org)
Gjøsund SH, Skjermo J, Forbord S, Jafarzadeh S, Sletta H, Aasen IM, Hagemann A, Chauton MS, Aursand I, Evjemo JO, et al (2020) Bærekraftig Fôr Til Norsk Laks. In: Sintef Rapporter. Sintef Oceans AS
Hoff H (2011) Understanding the nexus, background paper for the Bonn 2011 conference: the water, energy and food nexus. Stockholm Environmental Institute
Hoff H (2018) Nexus approaches to global sustainable development. Stockholm Environment Institute
Hoff H, Alrahaife SA, Hajj R, Lohr K, Mengoub FE, Farrajalla N, Fritzsche K (2019) A nexus approach for the MENA region - from concept to knowledge to action. Front Environ Sci 7:1–14
Hognes ES, Ziegler F, Sund V (2011) Carbon footprint and area use of farmed Norwegian Salmon. In: SINTEF fiskeri og havbruk rapporter. Sintef Fiskeri og havbruk
Intergovernmental panel on climate change (2018) Global warming of 1.5 °C. https://www.ipcc.ch/sr15/
International Renewable Energy Agency (2015) Renewable energy statistics 2015. Available via Renewable Energy Capacity Statistics 2015 (irena.org)
Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, Lowe I, McCarthy JJ, Schellnhuber HJ, Bolin B, Dickson NM, Faucheux S, Gallopin GC, Grübler A, Huntley B, Jäger J, Jodha NS, Kasperson RE, Mabogunje A, Matson P, Mooney H, Moore 3rd B, O'Riordan T, Svedlin U (2001) Environment and development. Sustainability science. Science 292(5517):641–642
Larmore C (1999) The moral basis of political liberalism. J Philos 96(12):599–625
Larmore C (1989) Liberal neutrality: a reply to James Fishkin. Polit Theory 17(4):580–581
Lazaro LLB, Bellezoni RA, Puppim de Oliveira JA, Jacobi PR, Giatti LL (2022) Ten years of research on the water-energy-food nexus: an analysis of topics evolution. Front Water 4:859891
Leck H, Conway D, Bradshaw M, Ree J (2015) Tracing the water–energy–food nexus: description, theory and practice. Geogr Compass 9(8):445–460
Lele SM (1991) Sustainable development: a critical review. World Dev 19(6):607–662
Liu J, Hull V, Godfray C, Tilman D, Gleick P, Hoff H, Pahl-Wostl C, Xu Z, Chung MG, Sun J, Li S (2018) Nexus approaches to global sustainable development. Nat Sustain 1:466–476
Liu J, Dietz T, Carpenter S, Alberti M, Folke C, Moran E, Pell A, Deadman P, Kratz T, Lubchenc J, Ostrom E, Ouyang Z, Provencher W, Redman C, Schneider SHW (2007) Complexity of coupled human and natural systems. Science 317:1513–1516
Matthews H, Hendrickson C, Matthews D (2014) Life cycle assessment: quantitative approaches for decisions that matter. Available via LCAtextbook.com – free textbook and other learning resources for the global LCA community. LCAtextbook.com
Mazza PI (2021) Concepts of sustainable development; a literature review and a systematic framework for connecting the role of education with the Sustainable Development Goals (SDGs). Int J Humanit Soc Sci 8(8):106–112
Mensah J (2019) Sustainable development: meaning, history, principles, pillars, and implications for human action: literature review. Cogent Soc Sci 5(1):1653531
Mensah J, Enu-Kwesi F (2018) Implication of environmental sanitation management in the catchment area of Benya Lagoon, Ghana. J Integr Environ Sci 16(1):23–43
Merriam-Webster Dictionary Available via Synergy definition & meaning - Merriam-Webster
Milne MJ, Gray R (2013) W(h)ither ecology? The triple bottom line, the global reporting initiative, and corporate sustainability reporting. J Bus Ethics 118(1):13–29
Miara A, Pienkos P, Bazilian M, Davis R, Macknick J (2014) Planning for algal systems: an energy-water-food nexus perspective. Ind Biotechnol 190(3):202–211
Moreno J, van de Ven D-J, Sampedro J, Gambhir A, Woods J, González EM (2023) Assessing synergies and trade-offs of diverging Paris-compliant mitigation strategies with long-term SDG objectives. Glob Environ Change 78:102624
Müller A, Janetschek H, Weigelt J (2015) Towards a governance heuristic for sustainable development. Curr Opin Environ Sustain 15:49–56
Nerini F, Tomei J, To L, Bisaga I, Parikh P, Black M, Borrion A, Spataru C, Broto V, Anandarajah G, Milligan B, Mulugetta Y (2017) Mapping synergies and trade-offs between energy and the Sustainable Development Goals. Nat Energy 3:10–15

Nicholson CF (2007) Review of methods for modelling systems evolution, discussion paper. International Livestock Research Institute, Cornell University, New York
Nussbaum M (2011) Creating Capabilities. Harvard University Press, Cambridge, Massachusetts; London, England. http://www.jstor.org/stable/j.ctt2jbt31. Accessed 11 Sep 2021
Nussbaum M (2001) Objectivity. New Lit Hist 32(4):883–906
Nussbaum M (1997) Capabilities and Human Rights. Fordham Law Rev 66(273):273–300. https://ir.lawnet.fordham.edu/flr/vol66/iss2/2
Nussbaum M (2003) Capabilities as fundamental entitlements: Sen and social justice. Fem Econ 9 (2–3):33–59
Peet R (1999) Theories of development. Guilford Press, New York
Rawls J (1993) Political liberalism. Columbia University Press, New York
Rotabakk BT, Bergman K, Ziegler F, Skåra T, Iversen A (2020) Climate impact, economy and technology of farmed Atlantic Salmon–documentation of the current state for fresh and frozen products to Asia and fresh products to Europe. In: Nofima rapportserie. Nofima AS
Scott CA, Kurian M, Wescoat JL Jr (2015) The water-energy-food nexus: enhancing adaptive capacity to complex global challenges. In: Kurian M, Ardakanian R (eds) Governing the Nexus. Springer Cham, pp 15–38
Segovia-Hernández JG, Contreras-Zarazúa G, Ramírez-Márquez C (2023) Sustainable design of water–energy–food nexus: a literature review. RSC Sustain 1:1332–1353
Sen A (2004) Elements of a theory of human rights. Philos Public Aff 32(4):315–356
Sen A (1990) Individual freedom as social commitment. New York Review of Books 37:49–54
Sen A (1985a) Commodities and capabilities. North Holland, Amsterdam
Sen A (1985b) Well-being, agency, and freedom: the Dewey lectures 1984. Journal Philos 82:169–221
Sen A (1984) Resources, values and development. Basil Blackwell, Oxford
Sen A (1980) Equality of what? In: McMurrin S (ed) Tanner lectures on human values, vol 1. Cambridge University Press, Cambridge
Stoddart H, Schneeberger K, Dodds F, Shaw A, Bottero M, Cornforth J, White R (2011) A pocket guide to sustainable development governance. Stakeholder Forum
Taguta C, Senzanje A, Kiala Z, Malota M, Mabhaudhi T (2022) Water-energy-food nexus tools in theory and practice: a systematic review. Front Water 4:837316
Terrapon-Pfaff J, Ortiz W, Dienst C, Gröne M-C (2018) Energising the WEF nexus to enhance sustainable development at local level. J Environ Manag 223:409–416
Thomas CF (2015) Naturalizing sustainability discourse: paradigm, practices and pedagogy of Thoreau, Leopold, Carson and Wilson. Ph.D Thesis, Arizona State University
Tjarve B, Zemīte I (2016) The role of cultural activities in community development. Acta Univ Agric Silvic Mendel Brun 64(6):2151–2160
Todaro MP, Smith SC (2006) Economic development, 8th edn. Addison-Wesley, Reading
Unesco World Water Assessment Programme (2023) The United Nations world water development report 2023: partnerships and cooperation for water. In: The United Nations world water development report 2023: partnerships and cooperation for water - UNESCO digital library
United Nations (UN General Assembly) (2015) Transforming our world: the 2030 agenda for sustainable development A/RES/70/1. https://www.refworld.org/docid/57b6e3e44.html. Accessed 17 Jan 2024
United Nations (2016) United Nations development programme human development report 2016. undp.org
United Nations (2020) United Nations development programme human development report 2020. In: The next frontier: human development and the Anthropocene. New York
Wolff J, De-Shalit A (2007) Disadvantage. Oxford University Press, Oxford
World Economic Forum (2011) Water security: the water-food-energy-climate nexus
Xu Z, Chau SN, Chen X, et al (2020) Assessing progress towards sustainable development over space and time. Nature 577:74–78
Yuan MH, Lo S-L (2021) Principles of food-energy-water nexus governance. Renew Sustain Energy Rev 155:2–9
Zhai TT, Chang YC (2019) Standing of environmental public-interest litigants in China: evolution, obstacles and solutions. J Environ Law 30:369–397