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Author:

Bendik Sele Gundersen

Supervisor at UiS:

Bjørn Ivar Kruke

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Contents

Figures:

Tables:

Abbreviations:

CVA = Conventional Vegetable Agriculture

OFA = Open Field Agriculture

CEA = Controlled Environment Agriculture

VF = Vertical farming

GHA = Greenhouse Agriculture

CPPS = Closed Plant Production System

Abstract

Agricultural operations and the agri-food system is essential to the continued survival of the human species. The maintenance of reliability, safety and security from farm to table is essential to any society. There is, however, a new kind of agricultural system emerging from the combination of innovations in LED-lightning, artificial intelligence, automated air condition and water-nutrient delivery systems, and a roster of sensors. These systems are in this paper collected within the acronym CEA (controlled environment agriculture), which serves to categorize agricultural systems such as vertical farms, high tech greenhouses and aquaponics. These agricultural innovations are finding their foothold within existing agri-food systems and recent research interest in the topic has gained momentum. There are several papers which outline their potential to have impacts on food safety, security and reliability. Even so, there are quite few papers which direct their research topic toward these aims. Therefore, the objective of this paper is to investigate how the implementation of CEA could affect the reliability of the agri-food system in Norway. The research has been conducted using an abductive method involving theory matching and literature review development alongside interviews with actors involved in the expansion of CEA systems in different countries. I have found that CEA has the characteristics of increased requisite variety, built-in passive controls and reduced negative externalities from their input and output compared to OFA and GH operations in Norway. However, CEAs are also geographically, policy and energy-grid contingent, which could hamper their scaling in areas which are not optimized for their development. This master's thesis has been developed with anyone interested in controlled environment agriculture, societal planning, societal safety and agricultural stakeholders in mind. With this thesis my wish is to contribute to the elevation of knowledge pertaining to the development of CEA systems and how they can be relevant in order to increase agri-food system reliability.

1 Introduction

Farming has in many ways evolved from a task which was physically, inherently local and largely unreliable in terms of yield (Tauger, 2021:38, 63), to an industrialized and globalized system (Dicken, 2014:424, 425), built upon a constant evolution (punctuated equilibrium) in innovations of technology such as irrigation, steam, internal combustion engines, synthetic fertilizers, pesticides and Genetically Modified Organisms (Fresco, 2015:433, 434). However, the contemporary agricultural system faces several existential problems. Within contemporary goals of international bodies such as the Sustainable Development Goals of the United Nations some major milestones include:

> Goal 2. End hunger, achieve food security and improved nutrition and promote sustainable agriculture.
> Goal 6. Ensure availability and sustainable management of water and sanitation for all.
> Goal 9. Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.
> Goal 11. Make cities and human settlements inclusive, safe, resilient and sustainable.
> Goal 12. Ensure sustainable consumption and production patterns.
> Goal 13. Take urgent action to combat climate change and its impacts.
> Goal 14. Conserve and sustainably use the oceans, seas and marine resources for sustainable development.
> 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, 2023: 8-21).

However, with 23% of global greenhouse gas (GHG) emissions resulting from the agricultural sector (IPCC 2019), while the sector already occupies roughly 38% of the world's land area for cultivation of crops and animal husbandry. Of which 33% is affected by anthropogenic degradation, and consumes 70% of global freshwater withdrawals (FAO, 2021: xi, 2, 10). In addition, overall food demand is set to increase by more than 50 percent by 2050 in order if we are going to feed 10 billion people (WRI, 2019). In many countries across the globe agriculture is the largest polluter of water. Only 44% of the water utilized for agricultural purposes by irrigation is absorbed by plants through evapotranspiration. The remaining 56%

is released into the water table or is absorbed into rivers and oceans. Nitrogen is the largest chemical contaminant in the world's groundwater (Mateo-Sagasta, 2018:3-4). 38 percent of the bodies of water located in the EU are significantly affected by pollution due to agricultural practices (Connor, 2015:71). The situation our agri-food systems face seems dire. However, it is estimated that increased diversification could allow for adaptive opportunities. The introduction of practices which underline the need for developing more soil organic matter, improving and establishing erosion control, increased fertilizer management, efficient and reliable crop management, establishing integrated production systems, increasing the pool of utilized genetic resources, balanced diets consisting of more plant-based foods, expansion low-emission animal food systems (IPCC, 2019:25-26). With no meaningful change adopted in the socio-technical systems which are critical to the human species we could be jeopardizing the safety of the human family.

> Contemporary environmental problems, such as climate change, loss of biodiversity, and resource depletion (clean water, oil, forests, fish stocks, etc.) present formidable societal challenges. Addressing these problems requires factor 10 or more improvements in environmental performance which can only be realized by deep-structural changes in transport, energy, agri-food and other systems. (Geels, 2011:24).

My interest in Controlled Environment Agriculture (CEA) and specifically the development of vertical farming came about due to the depiction of smart-city designs by authors such as Jaques Fresco and Dickinson D. Despommier (The Venus Project, n.d.) (Despommier, 2011). Due to the importance of agriculture in our daily lives, and the increasing pace of development in modern technology, it seemed fitting to focus on this pocket of socio-technical systems development. Existing literature about CEA isn't expansive, although publications on the topic are increasing in frequency. CEA systems, such as vertical farming, building integrated agriculture, high-tech greenhouses, aquaponics and their corresponding nutrient-delivery techniques (e.g. hydroponics, aeroponics) seems to mostly be analyzed in existing literature from the perspective of their characteristics and specifications when it comes to sustainability metrics such as water use, energy use, fertilizer use. Several papers collected in the literature review refer to food safety and security, however these topics are usually mentioned "en passant" and are not the focus of the papers. A review conducted by Dsouza, et al. (2023) only found one study examining the empirical validity of CEA to address food security (Dsouza, et al., 2023:8) Due to food security and safety being dependent upon the reliability and sustainability of agricultural operations, the need for a broad overview of the reliability and sustainability characteristics of CEA is needed. Therefore, the commitment to a holistic research topic and design method are also fitting due to a lack of existing in-depth data on the area of research. In this paper I will attempt to fill parts of this gap in the literature by utilizing a broad lens aggregated from a conceptual framework developed in order to link CEA to societal safety and sustainability literature.

1.1 Research problem

In order to understand why and how agri-food system innovations such as CEA should be implemented in order to increase reliability of these systems, we should first conduct an impact assessment of climate change. Since agri-food systems are particularly vulnerable to climate change we need to get an overview of where these vulnerabilities lie in order to extrapolate the potential impact CEA could have on their reliability. In addition, we also need to understand how they contribute toward climate change. This is due to view that reliability can’t be achieved by systems that actively contribute to their own failure. The implementation of CEA in local circumstances relies on regime and landscape push pull factors. If we wish to understand how CEA is applicable in local contexts to improve agri-food system reliability we need to attain an overview of these push and pull factors, I have conducted this research in the Norwegian context, but supplemental data has been gathered on other local contexts as well. Following, I will compare CEA and CVA in Norway to attempt to understand why CEA could be labeled as a part of a sustainability transition.

Due to the importance of the reliability of agri-food systems in order to ensure the food safety and security I would like to contribute a notable part of the paper toward exploring how the introduction of CEA might affect the reliability of these systems. Furthermore, since CEA is a grouping of a variety of technical production processes, I have chosen to contribute a part of the research topic toward generating descriptions of the different characteristics of CEA and CVA in their control structures and safety constraints. Furthermore, I will attempt to understand and explain why CEA exhibits requisite variety characteristics, and how this relates to the control structure and safety constraints.

Thus, our research problem is:

How can the implementation of Controlled Environment Agriculture (CEA) impact the reliability and sustainability of the Norwegian agri-food system?

The research questions are as follows:

- **Why do agri-food systems produce negative externalities? (Understand, explain)**

  To understand impact, we first need to establish the current structures of agri-food systems which are producing negative outcomes. It is of the perception of the researcher that the negative outcomes exist due to unexpected negative outcomes, therefore the literature review will focus on concepts and theories related to latent dysfunctions. While the document review will focus on the sources of vulnerabilities in agri-food systems.

  -What are the comparative impacts of agricultural operations' processes on agri-food system sustainability? (Assess impacts)

To establish if CEA can contribute to a sustainability transition in agri-food systems we need to compare the production method to conventional methods in contemporary agri-food systems in terms of their impacts on the external environment. To establish to which degree CEA could be viewed as part of a sustainability transition the 10-factor improvement metric from Geels (2011), and Elzen, et al. (2004) will be utilized to establish to which degree CEA offers sustainability improvements in comparison to average Norwegian CVA production metrics.

- **What kind of landscape and regime conditions influence the transition toward CEA adoption in Norway? (Understand, explain)**

To understand the implementation aspect of the problem question will utilize the Multi-Level Perspective-framework to investigate the opportunities, barriers, and motivating factors for CEA-actors.

- **What impacts can CEA's contributions have on the reliability of the Norwegian agri-food system? (explore)**
  -Why does CEA exhibit characteristics of requisite variety? (Understand, explain, evaluate)

In order to explore the impact CEA can have on the reliability of the Norwegian agri-food system we will establish if and how CEA has the capacity to maintain a greater amount of stability in operations, thus contextualizing the production method in terms of the law of requisite variety will be helpful as the law directly speaks to how systems maintain stability in outcome.

-What is the difference between CEA and CVA control structures and safety constraints? (Describe, explore)

To explore and describe the differences in CEA and CVA production methods in terms of their ability to operate reliably, the utilization of the STAMP-framework will be utilized to characterize areas within their associated control structure where control flaws could appear which puts the system state beyond its safety constraints.

-What novel contributions could the implementation of CEA afford to the Norwegian Agri-food system control structure?

Through the document review and analysis, the control structure of the Norwegian agri-food system will be modeled, and its vulnerabilities will be established. The STAMP-framework will be utilized to understand areas where the implementation of CEA in the Norwegian agri-food system could provide contributions to its reliability.

1.2 Limitations

The research has been limited to topic areas which are relevant to reliability, security and safety. Due to the broad scope as the research topic, which includes agri-food systems and their vulnerability to climate change. Sustainability is viewed as a major contributing factor to their reliability, security and safety. The decision has been made to not address economic factors, even though these factors certainly could influence the reliability of an individual farm and the momentum of scaling of CEA systems. Furthermore, this research is primarily concerned with the production aspect of agri-food systems, but our analysis is also broadly focused on the global landscape concerning agriculture and climate change, and on regime factors specific to the Norwegian agri-food system in order to allow for a more holistic approach to assess the reliability and sustainability of CEA in the discussion chapter. Therefore, the boundary of the system analyzed in this paper is drawn at the areas where CEA systems likely wouldn't contribute to change, at areas where societal functions likely won't affect the development of CEA, and at the economic side of this development. Also, while the sectors within the global agri-food systems related to the production of meat products is highly relevant to the reliability and sustainability of agri-food systems, these are not areas this paper is primarily concerned with as they do not relate to CEA. However, the global GHG output of vegetable and fruit production will be compared to meat production in order to contextualize the findings. In addition, I am under the perception that technologies such as LED lightning are going to follow the development path they're currently on (Morrow, 2008), becoming more efficient in the future and thus increasing the reliability of CEA in terms of their economics.

The literature review lays out a brief account of agricultural development in addition to previous findings on CEA in order to contextualize the research. The theoretical and conceptual areas of the literature review and subsequent conceptual framework have been developed iteratively in order to aid the discovery of theories and concepts. The literature chosen, have been deemed as good fits in terms of casting light on the reasons why CEA could contribute to an impact on the reliability and sustainability of agri-food systems. In order to provide context and holistic analysis of peripheral systems relevant to CEA, reliability and sustainability, the establishment of the mechanisms involved were regarded as essential areas of focus for the research. Therefore, the theoretical and conceptual areas of the literature review involve a range of literature concerning: Risk, reliability, requisite variety, system theoretic accident model and processes (STAMP) framework, man-made disasters, complexity and sustainability transitions.

2 Literature review

The literature review and the subsequent conceptual framework has been constructed to include previous research, theories, concepts and laws which are relevant in order to understand the research problems. The previous research will be presented according to their area of impact. First a description of CEA will be presented, then in falling order we will present landscape factors, regime factors and niche factors. We will go through understandings of risk; this is particularly useful when we are attempting to understand how the application and design of new technologies are related to risk. From there different typologies and perspectives on crises will be addressed to better understand their characteristics and their formative processes. Since crises in the modern world are closely related to social systems, complexity, fragmentation, and intractable systems these concepts will be laid out. Following, their relevance to the priorities in the Brundtland commission will be accounted for. From there on Multi-Level Perspective will be presented in order to understand how push and pull factors within social systems influence sustainability transitions. The stability of systems is addressed in the law of requisite variety, which organizational theorists have utilized in order to understand how reliability is maintained by organizations. However, we will establish that since HRO perspectives don't take on a systems theoretic (cybernetic) approach, they fall short of addressing how interactions affect reliability and safety in systems. Therefore, Leveson's STAMP-framework and how it relates to requisite variety will be accounted for in detail since I believe this is the best course of action in order to assess how the reliability of agri-food systems will be affected by the introduction of CEA.

2.1 CEA typologies

In this master's thesis Controlled Environment Agriculture is defined as a spectrum of closed plant production systems (Kozai, et al., 2006:62) which utilize hydroponics, aeroponics or similar closed-loop nutrient-water delivery methods (Gerrewey, et al., 2022:3) to grow plants within climate-controlled facilities. These facilities commonly include built structures that utilize shelves or towers which allows for vertical plant growth and LED lights (Dsouza, et al., 2023:2). Production system typologies which are included in this definition are: Vertical farms, plant factories and certain iterations of high-tech greenhouses.

The practice of farming vertically is an agricultural method for producing vegetables in layers of shelving by utilizing the space in the vertical axis, farms can utilize more space than a conventional vegetable farm. There are several different iterations of this idea. The most held idea of a vertical farm is indoors, using plant-optimized LED-lights, and utilizes the agricultural practice of hydroponics. These farms often don't use soil as a growth medium. The plants are in the early stages placed in rockwool, and at later stages the plants can be supported on the shelving itself. Water with all the nutrients needed for the plants are mixed with the water running through the shelving. When the water is rid of nutrients, it can be recycled by adding new nutrients back in. Iterations of this practice can be:

- Hydroponic vertical farms. Hydroponics is not a new agricultural technique; it gathered relevance due to the techniques resource conserving properties. In the United States vegetable growers located near cities in the United States had a hard time getting the manure and soil, mainly due to the decreased utility of urban horse stables as a result of the proliferation in use of the automobile and the subsequent development of highways and roads (Sholto Douglas, 1985:29-30). The hydroponic method consists of placing plants (often in soilless substrate) in nutrient rich water. It reduces soil-based cultivation issues such as insects, fungus and bacteria that thrive on soil, while reducing the risk of food-borne illnesses caused by manure-based fertilization. In also removes the need for a lot of manual labor such as weeding, tilling and dirt removal, in addition to increasing control of larger production areas (Al-Kodmany, 2018:7).
- Aeroponic vertical farms, utilize different method of watering the plants. Instead of letting the water run through the shelving, the plants are instead sprayed with controlled amounts of nutrient filled water-mist. The method has been shown to reduce water use significantly while providing better yields (Al-Kodmany, 2018:8-9) (Molenaar, 2023).
- Aquaponic vertical farms. Aquaponics is an agricultural production method on its own, but it is also in some cases combined with vertical farming for space efficiency reasons. Aquaponics is vegetable production combined with fish farming. Fish are contained in an aquarium, where they receive the water discarded from a vegetable farm. The fish then discrete their waste, which would in most cases be useless and discarded, but here it is transported back to the plants. Fish excrement is rich in all the

nutrients that plants need. This practice does in many ways simulate the natural life cycle of water in a controlled man-made biosphere (Al-Kodmany, 2018:10).

- Furthermore, vertical farms do not have to be CEA. The technique can be used in both greenhouses and outdoors. By using shelving, which is placed in a triangle shape, or by using vertical tubes or 30- to 90-degree shelving, you can grow plants vertically outside, thus mitigating the costs of LED-lights. A great example of a sun-lit vertical farm is Shockingly Fresh in Worcestershire, England (Horton, H., 2021).

2.1.1 CEA scales

PFAL's (Plant Factory with Artificial Lightning) is a term used to describe large-scale CEA production facilities. These are often constructed as vertical farms in order to utilize space efficiently. There now exist several PFAL's of significant sizes in many countries in the world. Some PFAL's which have sprung up in Norway are ONNA, located in Moss, and Urban Gartneren, located in Molde. Furthermore, Nordic Harvest, located in Denmark is one of Europe's largest vertical farms (Gallagher, 2021) and consists of 6970 m2, 14 shelf floors and has the production capability to produce 1,000 tons of vegetables a year (Peters, 2020).

Container farms are small-scale PFAL's fitted to containers, but this scale also accounts for the small-scale production often seen with hobby producers and microgreens producers.

In-store farms are located as near consumption centers as possible, such as within convenience stores, hotels and restaurants.

Appliance farms are smart indoor gardens which can be integrated into offices and homes. (Butturini; Marcelis, 2020:80-84) (Gerrewey, et al., 2022:1)

Integrated farms can be of any scale. They utilize unused space in urban areas to grow vegetables. Singapore is currently the de-facto world leader in integrated farms due to their mission to increased food-security with limited agricultural land and high rates of vegetable import (Diaz, 2021a) (Diaz, 2021b).

2.2 A brief account of agricultural- and CEA development

Open field agriculture (OFA) is the most practiced agricultural method to date, and it got its start in the Fertile Crescent around 10 000 years ago (Tauger 2020:1). The events that transpired formed the key to civilization. As Mark B. Tauger (2020) underlines; Agriculture was the prerequisite that made civilization possible at all. Without agriculture humans would not be able to create permanent settlements nor allow for specialization in processes which aren't aligned with the processes for gathering food. The reliable production of food was necessary for humans to manifest the ability to "form governments, strong armies, large-scale trade and markets, sophisticated writing and education systems, and other elements of a full-scale civilization" (Tauger, 2020:ix) However, in the Fertile Crescent, the agricultural development had limited success due to a lack of arable soils, which inhibited the vegetable farmers to develop farms beyond the coastal plains. Since humans had not yet established the practices of crop rotation or the use of fertilizers, the production of monoculture plants starved the soil of nutrients, leaving several areas with arable land desolate in terms of farming capacity (Despommier, 2011:51-52). In Japan, the dissemination of improved agricultural techniques, in particular due to the publication of the guidebook Nogyo zensho in 1697 resulted in an increase in irrigation, fertilizer use, more successful crop rotation practices and different specialization of crop production by regions (Tauger, 2020:61). The earliest record greenhouse agriculture (GHA) were crops produced in greenhouse structures are of Rome during 14 to 37 CE and greenhouses in the Joseon dynasty in Korea in 1450. In Rome artificial lighting was made possible by glazing the greenhouse structures with a transparent gypsum. Today, greenhouse structures are often made from polyethylene, and heated with propane or natural gas (Nemali, 2022).

The increased introduction of monocultures after world war I served as a great way to produce large amounts of high demand crops such as grain. However, the introduction of a single species of plants on fields which previously contained a large variety of different plants brought along several issues. Plants of a single variety are more prone to the onset of diseases and pests, and they consume the same nutrients from the soil. Therefore, the reliance of the farmer on technological inputs instead of the naturally occurring plant and animal services became widespread (Worster, 1990:1105). From the beginning of the 20th century central agricultural interventions were made in the wake of the Haber-Bosch process which allowed for the proliferation of synthetic fertilizer to the entire world, and the green-revolution with the introduction of Borlaug's high yield wheat varieties. In combination with extended use of pesticides, herbicides, made more available by globalized transport and communication, provided an astronomical impact on food security in a rather short amount of time. Without these innovations the earth would likely be a lot less populated (Fresco, 2015:432-434).

However, the changes made for the sake of increased reliability, efficiency and food safety have contributed to conditions which have adverse effects on food system reliability, and thus food safety. The negative developments affecting agriculture today such as declining soil fertility, run-off and pesticides affecting biodiversity and increased vulnerability to climate change, are largely related to agricultures dependency on oil. All synthetic fertilizers are produced with natural gas. Over-application of fertilizers negatively impacts soil organic carbon and useful organisms (Krasilnikov, et al. 2022). The most commonly used pesticide until the 1970s was DDT was based on fossil fuels, but it was shown to be dangerous to both humans and animals. The publication of the environmental science book silent spring in 1962 by Rachel Carson, a marine biologist, brought about public debate on the matter (Fresco, 2015:435) (Dunlap, 1981:7, 98). It took about thirty years (1939 to 1967) until regulators initiated the process of phasing out DDT use in the US (EPA, 1975). Inertia, strong economic interests with advantageous connections to governing institutions slowed down the implementation of regulations against DDT and other pesticides. However, the cumbersome scientific and regulatory foresight on the effects of these compounds weren't due to collusion between the chemical industry and governmental agents (Dunlap, 1981:237, 8). Rather, the policies of the Department of Agriculture and users of the product had brought about an "institutional and social framework that had grown up over the preceding half century." (Dunlap, 1981:8). Thus, the adherence to a particular set of structures and actors which were in line with normative views is to be expected. Even prominent scientific figures such as Wayland Hayes and Norman Borlaug were found to defend the use of DDT (Dunlap, 1981:142). Now, most pesticides are made to degrade over time, but many developing countries are still facing severe groundwater contamination from pesticide use (Tauger, 2020:172), and the focus has also moved towards other pollutants such as excessive nitrogen and phosphate in soil and water (Fresco, 2015:435). Pesticides also affect soil health, as the necessary microorganisms in soil can be harmed from improper pesticide application (Bisht; Miglani, 2019).

Agricultural production also relies heavily on petroleum-based energy inputs, since most countries today are dependent on international supply chain networks, food won't get to our tables without oil.

> Most people in the world live on foods to some degree produced, processed, and transported with fossil fuels. While foods have been transported increasingly since the

> 16th century, no major population has ever been this dependent for food on another non-food resource before. The problem with this dependency is that it has a finite life. In the 1950s, an oil geologist, M. King Hubbert, showed that oil wells follow a pattern of rapid growth to a peak (now called Hubbert's Peak) and then decline. He argued that the same pattern applied to total global oil production. The very likely prospect of declining oil production within the next century will require greater changes in farming than in any previous period in agrarian history (Tauger, 2020:172).

Controlled Environment Agriculture (CEA) is a collective term for technical advancements made in food production which allows for indoor the production of vegetables in a controlled environment. This practice differs from open field agriculture (OFA) and greenhouse agriculture (GHA) as CEA involves further technical measures to control the production environment in light, humidity, nutrient concentrations, CO2 concentration. These controls allow for the improvement of crop yields and quality of the produce (SharathKumar, 2020:724). Since CEA facilities aren't as affected by outside sources of disruption, they can be located in urban areas and cities, which could contribute to reductions in transportation emissions (Kalantari, et al. 2017:16-17). There isn't a hard line to be drawn between CEA and GHA, as there are GHA structures which have varying degrees of incorporation of controlled environment tools. However, in this paper we will choose to categorize GHA as glass or polyethylene structures where the growth medium is soil-based.

CEA seems to largely be both a reaction to and a natural progression of agricultural innovation. In this paper we mainly focus on CEAs that are designed as closed plant production systems such as vertical farms. In 1915 the concept of vertical farming was coined by Gilbert Ellis Bailey, an American geologist. Bailey argued that the ability to farm upwards instead of horizontally would enable more yield in a smaller amount of area (Bailey, 1915:3). It seems that the first building erected with the aim of vertical farming was in 1969 in Chorzów, Poland, led by the Austrian engineer Othmar Ruthner (Kleszcz, et al., 2020:1-2). James Sholto Douglas, who researched methods for hydroponic farming (soilless crop cultivation), envisioned that there was much room for progress in the practice:

> Amongst important developments in the field of intensive crop culture under controlled conditions, with the eventual goal of complete automation in mind, are such precision techniques as regulated ventilation in closed towers or plant factories, enrichment of the air with extra carbon dioxide to secure quicker maturation of crops,

> capillary irrigation with fiber-glass or polystyrene strips, use of photo thermostats, vegetative growth retardants and inhibitors carried through the atmosphere, and computer systems. It is considered that [computers] could measure and control light, air, aggregate temperature, humidity, and other connected effects. […] In short, soilless culture is currently progressing at ever increasing pace. New techniques are introduced in rapid succession, and the future holds out virtually unlimited possibilities. (Sholto Douglas, 1959:157).

Since this quote was written it seems that many of the things Sholto Douglas thought may happen are coming to fruition.

2.3 Capabilities of CEAs

Combining innovative farming methods with enclosed vertical structures and computer systems as a means for delivering nutrients has since the turn of the 21st century become more widely practiced with the increased efficiency in LED lighting and advanced robotics, water-, and nutrient delivery system technologies (Lauguico, et al. 2019:298) (Shamshiri, et al. 2018:8,13,16) (Hosseini, et al. 2021). The subsequent part of the literature review will go over the capabilities of CEA production systems and their limitations.

2.3.1 Weather events

As noted earlier, climate change has a vast impact on food production. There are both direct impacts on yield as a result of natural disasters and floods and can have indirect impacts on the quality and supply of water in a region. When we look at the current agricultural landscape, we see that drought has been the largest cause of mortality over the last 50 years (Douris, et al. 2021:16). Since plants grown in OFA are directly affected by weather conditions the reliability of production will always be dependent on uncontrolled external conditions. Production in GHA is also affected by weather conditions related to the variability of sunlight exposure. This variability also affects temperature and humidity. Humidity in GHA is usually regulated by natural ventilation, letting in air directly from the outside, this can allow for insects and diseases to get inside, which may necessitate pesticide use. Also, to regulate temperature GHA production facilities often utilize fossil-fuels (Kozai, et al., 2015:3-4). CEAs allow for reliability in food production to continue without perturbation from outside events such as droughts and floods. Weather patterns affect productive output of farms significantly by directly affecting yield. CEAs utilize closed plant production systems (CPPS) which reduces their dependency on uncontrolled or difficult to control factors such as soil fertility, climate conditions, weather seasons, insects and plant diseases and availability of external resources (Kozai, et al., 2015:4). Input factors such as water supply are thus less strained by CEAs (Al-Kodmany, 2018:28) since methods such as closed-loop water-delivery systems reduce water usage by 70 to 90% (Al-Kodmany, 2018:15, Stein, 2021:4) (Shamshiri, et al., 2018:16) (Despommier, 2011:162). Thus, they could also help to mitigate their dependence- and strain on water supplies during droughts. If the infrastructure of the facility is built to withstand large perturbations, they could also remain operational during storms and floods.

2.3.2 Control in production conditions

There is associated complexity with the control the growth environment even within CEAs as the control of humidity and temperature in cases of human error or technical malfunctions optimal thresholds could be interfered and create conditions which promote unsatisfactory conditions viable for the growth of bacteria. OFA has the advantage of natural air circulation and sunlight which inhibit such conditions. Bacteria can be transported by humans, making contamination a challenge to eliminate. To minimize these food safety risks, indoor farms implement strict sanitation protocols, including protective gear for workers. Innovative technologies like the integration of pest monitoring technologies such as: Ultraviolet light, air curtains, and HVAC filters that are employed to detect and prevent contamination. Achieving food safety in indoor vertical farms requires a combination of stringent protocols, controls, and advanced technologies to safeguard the crops such as the application of hair and beard nets, facemasks, and sanitized or single-use suits (Avgoustaki; Xydis, 2020: 41-42). Such implementations in a growth facility has the benefit of lowering or completely eliminating the need for the application of pesticides, insecticides or herbicides in CEAs such as vertical farms entirely (Al kodmany, 2018:5) (Avgoustaki; Xydis, 2020: 45) (Benke; Tomkins, 2017:17-18) (Despommier, 2011:161) (Germer, et al., 2011:242)) (Gerrewey, et al., 2022:5) (Kozai, et al., 2015:27) (Kozai, et al., 2006:68) (Liu, 2022:2) (Oh; Lu, 2023:138) (SharathKumar, et al., 2020:724) (Stein, 2021:2, 6). The controlled environment of CEAs allows for improved traceability of crops since the stages involved in plant production are subject to a high degree of monitoring and data collection. (Kozai, 2015:26, 237) (Benke; Tomkins, 2017:23). Thus, reducing CEAs dependency on external resource inputs while reducing the risk of improper chemical application affecting the safety of the produce and the external environment.

2.3.3 CEA and fertilizers

The use of fertilizers and pest controlling substances puts food safety and environmental sustainability into question (Dicken, 2014:424, 425). Many developing countries utilize animal and human feces instead of utilizing synthetic fertilizers, which increases the risk of parasites and disease (Kalantari et al., 2017). Fertilizers derived from livestock and humans have the potential of carrying diseases. While the increased use of fertilizers in developing countries can increase human well-being by reducing malnutrition, it also increases the disease vector (Rohr et al., 2019:446, 450). Fertilizers are essential in conventional agriculture. Crop rotation have generally been replaced with increased use of fertilizers in the agricultural landscape. As a result, the worlds capacity for food production will decline if fertilizers become scarcer. In 2019 Russia was the global source for 15% Nitrogen exports, 14% Phosphate exports and 19% Potash exports. Thus, agricultural techniques which rely less on fertilizers may be relevant to reduce mutual dependence.

Since CEAs usually are operated in enclosed systems there is little-to-no spread of fertilizers to the surrounding environment, they reduce the risk of eutrophication by containing recycling the nutrients used in the process, and as a result also utilizes less fertilizers (Winiwarter. et al., 2014:29). Greenhouse crops in open irrigation systems are irrigated with a large amount of water compared to closed irrigation systems. Greenhouse crops in open irrigation systems receive 20 000 000 liters of water per 10 000 m2 per year, or 2000 liters per m2. About 50% of this water disseminates into the surrounding environment. The common nutrient solution of fertilizer contains 150g of nitrogen per 1000 liters (Bar-Yosef, 2008:342).

The reduction of nitrogen use seen in two studies looked at by Bar-Yosef (2008) on closed circulation irrigation systems found that there was one case of 30% saving in nitrogen application and one case of 50% saving of nitrogen application (Bar-Yosef, 2008:407). Furthermore Liu et al. (2022) seems to corroborate this as they found a 37% reduction in the nitrogen footprint, and a 36% reduction in the phosphorous footprint, observed in a study of 21 operating vertical farms in Japan (Liu, et al. 2022) Winiwarter et al. (2014) found that VF had the potential to reduce release of nitrogen released to the environment 10-fold, in comparison to CVA, while contributing to a moderate decrease in nitrogen related GHG emissions (Winiwarter, et al., 2014:41). Kozai, et al. (2015) also estimated a high rate of fertilizer use efficiency in CEA compared to greenhouse and OFA. The only reason one stops the recirculation process in closed-loop irrigation systems is to drain due to build-up of certain parts of the nutrients in the fertilized water, or if there has occurred contamination in the system. The system usually only needs to be drained about twice a year (Kozai, et al., 2015:79). Bar-Yosef (2008) argues that even though there are significant advantages of closed loop irrigation systems at a national level the introduction of regulation which charges farmers for nitrate pollution might be necessary due to the high costs of initial investment in such systems (Bar-Yosef, 2008:342).

2.3.4 Limitations of vertical farms

Vertical farms present an exciting opportunity for crop cultivation, with the potential to grow a wide range of crops beyond leafy greens and microgreens. Research indicates successful vertical cultivation of cereal crops like strawberries, potatoes, beans, and wheat (Oh; Lu, 2022:137). However, plants suitable for farming in vertical structures should be 30 cm or shorter due to the distance between shelving or levels are usually 40cm in order to optimize yields per m2. In addition, crops with lower economic value and longer growth periods may not be ideal due to the energy costs associated (Kozai, et al., 2015:4) Despite this, research by Germer, et al. (2011) indicates that vertical agriculture could provide value outside of internal revenue generation by providing environmental protection. They conclude that 15 000 € per acre per year from the implementation of rice production in vertical farms, while in theory being able to increase rice production by 200 times the average global rice production yield (Germer, et al., 2011:243, 249).

2.4 CEA viewed from the Multi-Level Perspective

While we’ll go over the Multi-Level Perspective framework in more detail in section 2.5 of the literature review, it is relevant to bring up that the literature review found one paper which analyzes agricultural systems utilizing the Multi-Level Perspective developed by Ari Rip and Renè Kemp (Rip; Kemp, 1998), and Frank Geels and Johan Schot (Geels, 2005) (Geels; Shot, 2007) (Grin, et al. 2010). Here, Petrovics & Giezen (2022) underline that in the context of agricultural innovations such as vertical farming, the dominant regime is in this case the current food system, which can be characterized by an increased homogeneity and agglomeration of distributions centers and retail services, transportation networks which cover vast distances and industrialized agricultural processes. The landscape can be characterized by an approaching food crisis, neoliberal capitalism, globalization, and negative developments in the nitrogen cycle (Petrovics; Giezen, 2022:789). VF as a niche has emerged due to landscape drivers appearing from the global- political, demographic, technological economic and environmental -context due to it's prospective of providing a more sustainable avenue for food production than CVA, all the while reducing resource use, increasing yield and providing enhanced food security and safety. As a result of these numerous predicted and anticipated positive advantages, funding and competitive interest on the niche level has increased. However, landscape pressures related to political and economic factors; Notably the allocation of agricultural subsidies on the regime level by institutions such as the EU through the Common Agriculture Policy (CAP) which often excludes innovative agricultural practices and serves to uphold the contemporary regime structure. In addition, the organizational practices resulting from venture-capital funding creates internal conditions which affect the relationship between niche actors, damaging the upscaling potential of VF toward the regime level. The internal conditions consist of competition, knowledge silos, short-term profit seeking and distrust and result in manifest functions such as patenting of intellectual property, absence of cooperation and shared information. While Petrovics & Giezen (2022) maintain that landscape drivers have to a large extent been the foundation for the development of VF, landscape pressures also lead to constrictions of the evolution of VF into a fully-fledged part of the agricultural regime because of political and economic structures (Petrovics; Giezen, 2022:786-804).

As VF and CEA could provide integrated agriculture in urban environments, they could have positive impacts in regards to shortening the supply chain and reducing the energy used for refrigeration and GHG emissions resulting from transit (Romeo, et al. 2018,544). Oh & Lu (2023) note that farmers will be able to benefit from the reduced crop losses, enhanced efficiency and more stability in supply chains in conjunction with improved sustainability of CEA methods such as VF (Oh; Lu, 2023: 135). Thus, the landscape pressures seem to have informed the actors developing these niches. However, Petrovics notes that in order for developments such as VF to contribute to a sustainability transition in agriculture the right context is needed. If VF is fueled by inputs from high-carbon energy grids such as one powered by natural gas or coal, their resulting GHG emissions are a lot higher than both OFA and GHA production systems (Burgos; Stapel, 2018:12-13) (Petrovics, 2022:800). In addition, the contexts where alternative supply chains and distribution logistics are developed are where the true potential for CEAs such as VF. The one-directional nature of food-chains in the current agricultural regime is argued to both be exemplifying the linear transactional nature between the social sphere and the supply sphere, while also revealing the diversion of biological and socio-economic systems. Thus, single supply end solutions such as VF will not be able to enable a sustainability transition in agriculture on its own, the right context is required, such as the development of low-carbon energy grids and local direct to consumer networks (Petrovics; Giezen, 2022:790, 798-799).

2.5 CEA and indoor agriculture during crises

Since vertical farms open the opportunity for producing food near areas where the consumption of it is at its highest, like cities and towns. Vertical farming has gained steam in in high density areas in Japan, in particular the development increased as a reaction to the Fukushima earthquake and nuclear disaster (Harding, 2020). After the tsunami that had catastrophic consequences in Fukushima, Japan in 2011 there were also efforts to rebuild agricultural solutions in the affected areas where farmers had lost their crops. Recovery efforts were promoted by the Soma city authority, which asked the Tokyo University of Agriculture to provide assistance in creating agricultural organizations which could aid in post-disaster recovery. The university assisted these organizations in gathering information about how the local farmers wanted the development of farming activities to take place. In addition, the university had participating visits in the areas affected with the goal of maintaining collaboration between the marketplace, agriculture and industry. (Monma, et al. 2015: 35) in order to alleviate food production of the stresses caused by salt water and radiation on crop fields, farmers constituted mutual strategies for the development of hydroponic strawberry farms (Monma, et al. 2015: xii).

The combination of interventions and innovation in the areas of technology and food-consumption have the largest potential for reduction of GHG emission, while also likely being the most effective path for maintaining food security. Thus, interventions and innovations which only affect one of these aspects are not capable of meeting the future challenges of our agri-food systems. Thus, past measures such as the increased use of synthetic fertilizer are not applicable when we implement sustainability into our goals of maintaining food security (Smith, 2013:27).

> Measures that improve the efficiency of agriculture (i.e. that maximize food outputs relative to agricultural inputs), or that reduce demand for food products (i.e. dietary changes and reduced waste) will be beneficial for both food security and GHG emission reduction – these are the improvements that need to be made if we are to rise to the biggest challenge humanity will face in this century." (Smith, 2013:27)

As previously mentioned only one study was found to examine the empirical validity of CEA to address food security by Dsouza, et al (2023) in their scoping review (Dsouza, et al., 2023:8). This paper was produced by Abdullah, et al. (2021) where their case research attempted to outline the potential for self-sufficiency provided by indoor and vertical farming. Since reliance on imported food products increases vulnerabilities to food shortages the authors wanted to map the potential contribution CEA could have for food security in the Gulf Cooperation Council region. The paper showed that the introduction of CEA could allow the state of Kuwait to entirely cut the imports of tomatoes, cabbage, potato, green peppers, carrots, and lettuce by use of 0,1 km2 of vertical farms or 15 km2 of indoor farms (Abdullah, et al. 2021). This research illustrates the food security potential CEA implementation could afford countries with limited access to fertile land or hospitable plant production environments the benefit of local food production with little to no intervention applied to the natural environment.

2.6 Toward a conceptual framework

2.6.1 Risk

To be able to understand why risk we first need to define the term risk. Risk has been a term widely used and understood throughout the history of humanity. The term is theorized to be derived from a variety of etymological sources. Aven (2012) notes that the most common sources of the word seem to be “to dare” or “hazards encountered while sailing a ship”. Today the term is mostly used to describe:

- “(Exposure to) the possibility of loss, damage, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility.
- A hazardous journey, undertaking, or course of action; a venture.
- A person or thing regarded as likely to produce a good or bad outcome in a particular respect; a person or thing regarded as a threat or source of danger.”

(Aven, 2012:35)

In the modern world there have been many attempts at defining risk, as it is a concept which has many definitions associated with it. There is no widely accepted definition of risk. In literature on the topic, risk is often defined in terms of expected value, probability distribution, uncertainty, or as an event (Aven; Renn, 2009:1). In a 2009 paper Aven & Renn attempted to examine two definitions of risk, which are derived from 10 different definitions which fit two categories-:

"

1. Risk is expressed by means of probabilities and expected values
2. Risk is expressed through events/consequences and uncertainties "

(Aven; Renn, 2009:2).

-and evaluate their usefulness for risk research and management. They ultimately conclude that while these definitions provide a solid foundation for understanding risk, they may differ from how risk is commonly understood and used in most applications, which can lead to conceptual difficulties. From the result of their analysis, they conclude that a useful rephrasing of the two definitions could be: "Risk refers to uncertainty about and severity of the consequences (or outcomes) of an activity with respect to something that humans value." (Aven; Renn, 2009:1) Risks are not usually sought after for their own right but are rather attached as a side-effect to a process of transformation of our environment with the goal of serving our wants and needs (Renn, 2008:6). The distinction between hazards and risks are laid out by Hohenemser, et al. (1983) as: "Hazards are threats to humans and what they value, whereas risks are quantitative measures of hazard consequences that can be expressed as conditional probabilities of experiencing harm." (Hohenemser, et al., 1983:379) Furthermore, Leveson (2012) notes that hazards are conditions or states within a system which can lead to accidents and losses when presented with a catalyst in the form of worst-case environmental conditions. She contrasts hazards with failures since a failure transpiring doesn't imply the potential for an accident or loss (Leveson, 2012:184). The failure of a lamp doesn't mean that an unsafe condition is present. However, if the lamp is in the operating room of a hospital, and the environmental conditions are set during surgery, a lamp with a high probability of failure can be viewed as a hazard. Considering this, hazards can be viewed as system states that are imperative for accidents and loss to materialize. While failure tells us something about the reliability of a particular area of a system, which could affect the overall safety of the system depending on the overall state of the system.

2.6.2 Socio-technical hazards and causality

When the consequences have appeared, we no longer refer to the event as a hazard or risk, but rather an accident, disaster, catastrophe etc. The Seven steps of a risk chain: The example of nuclear energy in figure 1, adapted by Renn (2008) and IRGC (2005) from Hohenemser, et al. (1983) describes how risk assessment and management can be used at different steps of an action chain to serve preventative and reactionary actions to reduce risk (Renn, 2008:7) (IRGC, 2005:21). Figure 1 shows us that early preventative action when dealing with technological hazards is in many ways is preferrable, because it allows us to change course before consequences arrive.

Figure 1: Seven Steps of a Risk Chain: The Example of Nuclear Energy

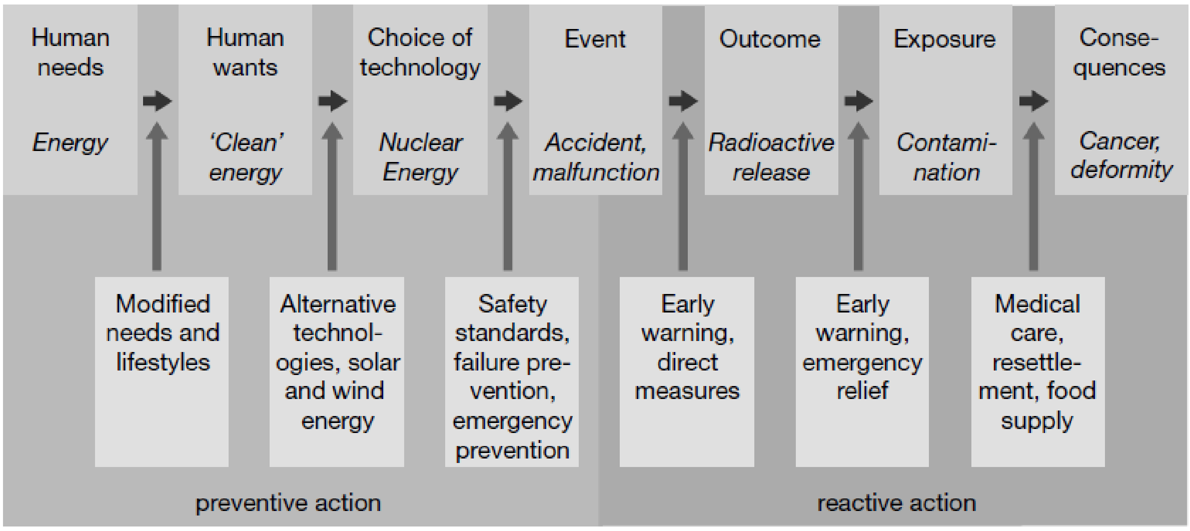


Figure 1. Seven steps of a risk chain (IRGC, 2005:21).

The causal sequence which Hohenemser, et al. (1983) has visualized in figure 1, implies that the choice of technology, which stems from human needs and wants, is the earliest area of hazard description. Intentionality is regarded as the hazard descriptor of the choice stemming from human needs and wants. As such we can mitigate risks earliest in the sequence by modifying needs and lifestyles, and we can measure hazards in the technology used by looking at intentionality (Hohenemser, et al., 1983:279).

However, as Leveson (2012) argues: “Although the first event in the chain is often labeled the initiating event or root cause, the selection of an initiating event is arbitrary and previous events and conditions could always be added.” (Leveson, 2012:20). Hohenemser, et al. (1983) themselves noted that their implicit assumptions in their research was that technological hazards are derived from a “single domain” and that they are usefully explained by linear causality (Hohenemser, et al., 1983:384). Events which are familiar, events that are felt could be corrected, events associated with the last causal link before lack of information, and political, or normatively accepted events are often chosen as the root cause. Humans are often viewed as the cause of an accident because it is difficult to continue the causal chain *through* a human (Leveson, 2012:20). Fittingly, the latter is in this case highly relevant as it is may be hard to continue the causal chain beyond human needs as they may arrive from a confluence of factors, they are emergent.

In supplementation to this view, as Turner & Pidgeon (1997) note, the understanding of the causes of disasters as purely technical, allows for a limitation in scope which could be detrimental to risk assessment and management. We should rather view the causes of disasters as socio technical. As it they are a confluence of technical, social, and organizational processes and the interaction of these which manifest the phenomena we today label as disasters (Turner; Pidgeon, 1997:3). The relationship between human needs and wants, the causal sequence of the development and implementation of technology and the structures assembled by humans to facilitate these technical manifestations create an interplay between human- and technical systems.

2.7 Reliability in organizations

In order to understand how reliability is affected we need to first look at what reliability is. Hannan and Freeman define reliability as: “[..] unusual capacities to produce collective products of a given quality repeatedly” (Hannan; Freeman, 1984:153). They also describe the two main competencies of organizations: reliability and accountability. Reliability refers to the ability of an organization to consistently produce collective products or services of a certain minimum quality. Accountability refers to the ability of an organization to rationally account for its actions and decisions, including the use of resources and the processes by which outcomes are produced. These competencies are important because they enable legitimacy and support which serves to gain the trust of potential members, investors, clients, and other stakeholders (Hannan; Freeman, 1984:153).

Schulman (1993) argued that organizational reliability is accomplished through the facilitation of variance and slack. Resource slack defines a both positively and negatively loaded term which is related to the management of time, capital, workers etc. The resources which are available to the organization at any moment. By maximizing the output of an organization, you are on one hand increasing its performance and profitability, but also depriving the organization of redundancy. In the event of an unexpected accident, you would have less resources to deal with it (Schulman, 1993:354, 371). Control slack relates to the individuals in the organization and their ability to respond with agency in terms of their work. If the employees are coordinated by a central authority the organization may be more efficient and directed in its actions. On the other hand, the organization also loses flexibility, while also limiting the individuals within to solve or protect themselves from the ills which may come with centralized authority (Schulman, 1993:354). One example of such ills could be an employee on a tight schedule which would be fired if they refrained from their duties. If a problem in need of investigation appears the individual may have to ignore it to maintain their position in the organization. Both resource slack and control slack are commonly referred to as redundancy. Conceptual slack concerns the differing opinions which are born out of variance in analytical perspective among the agents within an organization (Schulman, 1993:364). Thus, providing differing "theories, models, or causal assumptions pertaining to its technology or production process." (Schulman, 1993:364).

2.7.1 Reliability in rapidly changing environments

Vogus & Welbourne (2003) found that IPO-firms during the dot com era, which were involved in constructing computer innovations, resembled HRO's in certain ways. The firms involved in innovation were enveloped in "complex, rapidly changing, and tightly coupled organization-environment relations" (Vogus; Welbourne, 2003:878).

In order to survive, organizations that are do not have the ability to incur the characteristics of as Hannan & Freeman (1984) termed it: Structural inertia. Instead, they must become reliability seeking, by scanning the environment and responding elastically to changes (Kruke; Olsen, 2005:283). Such innovative organizations do not exemplify the same kind of reliability as defined by Hannan & Freeman: "(..) unusual capacities to produce collective products of a given quality repeatedly" (Hannan; Freeman, 1984:153). Instead, these organizations are dependent upon being reliable in capacities of innovation to stay in business (Vogus; Welbourne, 2003:878). Brown & Eisenhardt (1997) viewed the conclusions of early organizational theory outdated, which largely viewed organizations as static entities, while they found that these innovation driven organizations operated in an environment which calls for constant change and adaptation based on new inputs (Brown; Eisenhardt, 1997:4-8).

However, even though organizations may be reliable, that doesn't necessarily equate to their operations being safe.

2.7.2 Requisite variety in organizations

As mentioned by Schulman (1993) having variety in different backgrounds and perspectives within an organization may help the team to understand a problem differently, instead of just relying on one conception of what the cause might be, and therefore solving it more efficiently. This variety was acknowledged by Weick, et al. (1999) (1979) to be a form of requisite variety. "It's because of requisite variety that organizations have to be preoccupied with keeping sufficient diversity inside the organization to sense accurately the variety present in ecological changes outside it." (Weick, 1979:188). An organizations boundaries are set by what they are not, and therefore they are often surprised by what are outside their purview since everyone inside these boundaries focus on a set of tasks decided by the organization. Internal complexity is required in order to handle external complexity. Thus, HRO's restrict the simplification of information by increasing requisite variety. They note that HRO's aren't just characterized by the heterogeneity in perspectives, they also utilize structures that enable dialectic processes between parties in disagreement. In addition, they employ decentralization by delegating authority to the local level during contexts associated with high complexity (Weick, et al., 1999:41-42, 60). Thus, reliability is viewed by these authors as organizational structures that allow for more reliable operations, and thus more safe operations. The common theme seems to be that reliability is stability in output, but *not* stability in operations. Variety in operations is necessary in order to maintain stability in output.

2.7.3 Reliable, but unsafe?

What should be addressed here is the scope of reliability and HRO literature. Since Hannan & Freeman (1984), Schulman (1993) and Weick (1999) largely focus on the reliability of organizations largely due to their social structures, it may be hard to view CEAs through these perspectives entirely due to their reliability largely being attributed to their technical applications. Therefore, the inclusion of Nancy Leveson's system theoretic perspective is of use. Her contention with HRO-theory is in part related to the conflation of reliability and safety. They are not necessarily aligned system aspects. A system can very reliably be unsafe, and it can operate safely while being unreliable. They can also be at odds with one another, as an increase in reliability could decrease safety and vice versa. In some organizations safety is represented as the goal of its actions, while in others safety is represented by constraints which are put on its actions in order to achieve their goal (Leveson, 2012:10). While the capacity to consecutively produce products of a certain quality is relevant to agri-food systems as their mere functioning is indicative of the safety of societies, only looking at the reliability of a single part, component, or process doesn't necessarily tell us the whole story. Like Hannan & Freemans definition, the term reliability in engineering is viewed as the probability that a component will continue its intended function over a given time frame and conditions (Leveson, et al., 2009:234).

2.7.4 The momentum of change in HROs

Most changes made in HROs, at least in the classic HRO industries such as aviation, nuclear power plants and space programs, are introduced slowly over time and followed closely. In addition, the changes are often introduced for the sake of safety itself. HROs are viewed as reliable because they operate with incredibly low failure rates in comparison to other systems their size. However, the structure of HRO's necessitate failure free operation, it is built into their design because safety is usually one of their primary operational goals. The reasons for most of HROs operations in day to day is to ensure safety. The actors within HROs have near complete knowledge of the systems they are operating, which results in their practices containing low levels of uncertainty due to their stable technical processes and their apprehensive and watchful implementation of changes (Leveson, et al., 2009:238-239). In comparison the small innovative firms looked at by Vogus & Welbourne (2003) and Brown & Eisenhardt (1997) would have a hard time following this formula, as their operations were enveloped in constant change. If they were operating systems that were critical for safety, they might not be able to operate in this way. Most organizations have other goals beyond safety, and these goals can contradict safety goals, creating goal conflict. In competitive markets technological innovation and adaptation is often required in order to achieve their primary goals: "Management statements that safety is the primary goal are often belied by pressures on employees to bend safety rules in order to increase production or to meet tight deadlines." (Leveson, 2009:239).

2.7.5 Complexity and tight coupling

In Perrow's theory of Normal Accidents, the idea that accidents and disasters become more likely due to the combination of complexity and tight coupling in systems which only can be solved by reducing complexity and tight coupling (Perrow, 1984). Leveson's (2009) contention regarding the Normal Accident view consists of two arguments. The first is that Perrow's view of coupling and complexity doesn't consider the kind of hazard involved, it's only concerned with the likelihood of accidents happening based on these factors. The second is that Perrow didn't categorize the types of complexity and coupling which increase the likelihood of accidents, all kinds of complexity and coupling were denoted as the same. Furthermore, all the socio-technical systems within an industry are assumed to have the same kinds of complexity and coupling, instead of separating these socio-technical systems based on their engineered design properties (Leveson, 2009:229-231). However, Leveson agrees with Perrow that redundancy doesn't necessarily reduce risk as assumed in much of HRO theory as it introduces complexity and encourages risk taking. In addition, failure isn't always limited to active parts and components in cases such as common cause and common mode failures (Leveson, 2009:233).

2.8 Requisite variety and systems theory

Ross Ashby (1956) coined the law of requisite variety. The law was based on developments in telecommunication science using the previous works of Hartley (1928) and Shannon (1949). Ashby showed that the law applies to any system which conducts a process of regulation. In order to gain a certain outcome, the law states that the amount of input states a system is exposed to need to be equivalent to the number of states of the regulatory process within the system (Ashby, 1956:202) (De Raadt, 1987: 517, 521). With Ashby's law of requisite variety, we can understand regulation as a central point of the reliability of any socio-technical system, since it deals directly with regulating towards a desired outcome.

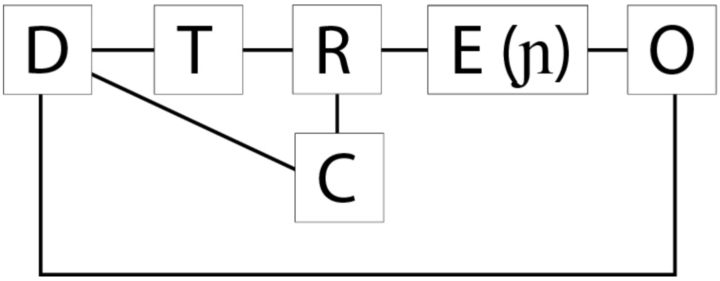


Figure 2 A model of requisite variety in a system (based on Ashhby, 1956)

The law of requisite variety states that that regulation (R) is needed in order to reduce the amount variety in a system. Regulation is introduced by increasing variety as a counter to the variety exerted by inputs, outside disturbances (D) through a process of transformation (T, Ashby refers to this as “Table”). The law states that in order to maintain stability in outcomes (E), the variety of the regulator (R) must match the variety of the disturbances (D). The controller of the regulator (C) provides input in order to obtain specific desired outcomes (ɲ), (Ashby, 1956:200-213) these are desired system states, such as goal conditions (Parsons, 1951) or safety constraints (Leveson, 2012). The concept of requisite variety also shows us that the flow of information to the outcome (E) also decreases with the introduction of regulation, and the subsequent loss of variety felt by the outcome (E). In figure 2 we have added a separation between outcome and output in order to differentiate between short term outcomes (E) for the system and outputs (O) which are fed back into the system in the form of external input from (D). An analogy for requisite variety proposed by Ashby is the temperature-controlled room. By reducing the variety of the disturbances (D), the weather outside, by introducing a regulator (R) in this case the air condition. In this case the desired outcome (ɲ) the temperature-controlled room, inhabits less information about the weather outside (D) due to the regulator. Also, if the regulator fails, the outcome (E) will inhabit more information about the disturbances (Ashby, 1956:200-213). There are different ways of applying the law of requisite variety. We could add detail with a controller which controls the regulator. In this case the controller and the outcome would be closely related, as the person affected by the temperature is inside the room. Then, the controller would have both information about the outcome and the disturbances as they are receiving information about the temperature from the regulator via a display (feedback).

2.8.1 Passive and active controls

In engineering, passive protocols are those that maintain safety by their presence. The system fails into a safe state or simple interlocks are used to limit the interactions among system components to safe ones. Some examples are shields or barriers such as containment vessels, safety harness, hardhats, passive restraint systems in vehicles and fences. In contrast active controls require some actions to provide protection. These involve detection, monitoring/detection, measurement, interpretation/diagnosis, response/recovery/fail safe procedures. These actions are usually implemented by a control system which now commonly includes a computer. Failure modes in active control systems are greatly increased over passive design, as is the complexity of the system component interactions. The complexity of our designs are reaching and exceeding the limits of our intellectual manageability with a resulting increase in component interaction accidents and lack of enforcement of the system safety constraints. However, there are often very good reasons to use active controls instead of passive ones, including increased functionality, more flexibility in design, ability to operate over large distances, weight reduction, and so on (Leveson, 2012:77).

2.8.2 Maintaining dynamic equilibrium

Open systems can be characterized as systems that can be transposed to imbalance by inputs from and to their environment (D and E). Closed systems are systems which are settled or settling into an equilibrium state since they are made up from unchanging components. In order to maintain dynamic equilibrium in open systems (maintaining E within ɲ threshold) a controller must have a goal condition, for example to gain a certain outcome (ɲ). An action condition, the controller has to be able to impact the state of the system (R). A model condition, the controller needs to have a model of the system (Knowledge about E, R and D). An observability condition, the controller has to be able to receive information about the state of the system (feedback from E) (Leveson, 2012:65). As recently presented in the temperature-controlled room example, if the controller and the outcome are closely related, the information about the disturbances accessed by the controller will be higher in opacity. The further away they are from each other, both spatially and temporally, the blurrier the information will be to the controller. Time lags impact the flow of actions and feedback from the controller. Standards, laws, and regulations can take years to be adjusted, while technological change may happen at a much faster pace. Those which are closest to the outcome, or controlled process will have a more detailed and responsive picture of accidents than those in higher levels of a control structure (Leveson, 2004:20).

In view of the organizational theory previously discussed this could be viewed as two different sets of organizations. One, which is larger and therefore more stable, it can withstand a larger variability in outcomes, and thus have a higher threshold in safety constraints (ɲ), compared to the other, a small innovative firm. The inert organization are often more closed in character than small firms, but this assumption relates to their inputs, as their outputs usually exert large pressures on surrounding systems. This is because a large financial loss or accident to an innovative small organization could be tiny to the inert large organization, but the output of a large inert organization could affect many smaller organizations. In a large inert firm, the controller will have more time to adjust in response to the disturbance before safety constraints are breached. However, the advantage of the innovative small organization is that it takes far less resources and regulative procedures for the controller to adjust the regulator based on new input, and the controller may also be more in tune with the outcome of the process due to short spatial and temporal distances between them. A river will exert a large amount of influence on the surrounding environment. One can change the course of a river, but it usually takes a large amount of time and energy to do so.

2.9 STAMP – Systems- Theoretic Accident Model and Process

The causality model brought forward by Leveson provides an understanding of accident causation which attempts to establish how interactions between system components and system states lead to hazardous states which in turn result in accidents. Here the causes of accidents are viewed as a control problem, not a component problem (Leveson 2012:75, 91). An accident could be defined as the loss of life, but it can also encompass other losses which are deemed unacceptable, these could be financial, information and equipment losses (Leveson 2012:75). The criteria for specifying a certain event as an accident should be grounded in the severity of the loss being of such significance that it should be accounted for in the design and tradeoff process. From there the hazardous system states which could lead to an accident should be established (Leveson, 2012:267). According to the STAMP model, an accident is caused by two categories of violation in safety constraints; the lack of enforcement of safety constraints by the controller, and adequate enforcement of safety constraints but these control actions were not followed during operation. Lack of enforcement of safety constraints can occur due to; control actions necessary for upholding safety constraints not being provided, control actions are provided at the wrong time, and control actions are provided but they contradict the safety constraints (Leveson, 2012:92). The causal categories which can be applied to accidents can be presented by: “The controller operation, the behavior of actuators and controlled processes, and communication and coordination among controllers and decision makers” (Leveson, 2012:92).

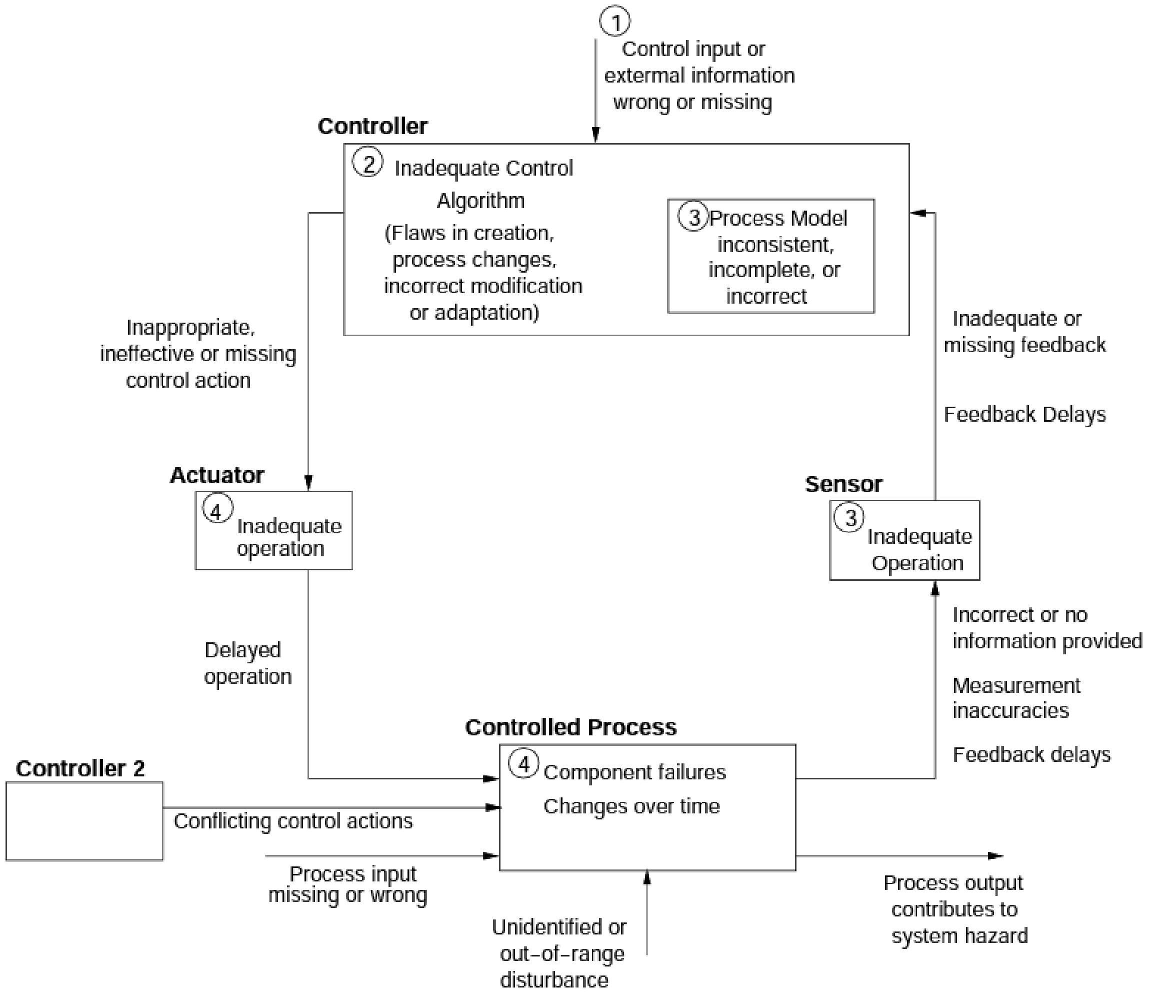


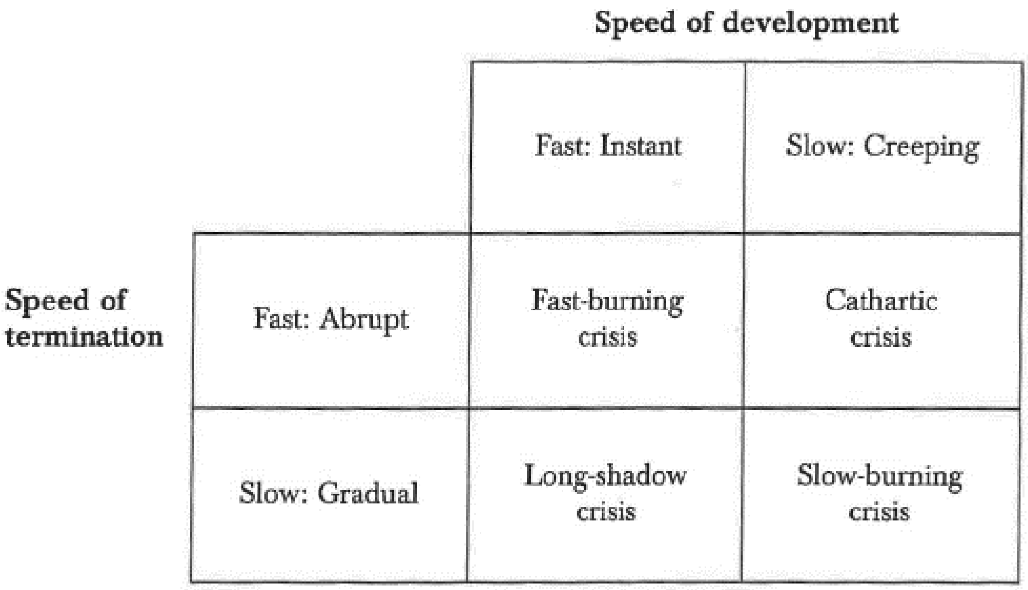
Figure 3 Classification of control flaws leading to hazards (Leveson, 2012:93)

2.10 Crisis

According to a literature review conducted by Al-Dahash, et al. (2016) on the differences between the crisis, disaster and emergency terminologies, it was found that disasters typically describe “sudden unforeseen events with natural, technological or social causes that lead to destruction, loss and damage” (Al-Dahash, et al., 2016:2).While a crisis is a “disruption that physically affects a system as a whole and threatens its basic assumptions, its subjective sense of self, its existential core" (Pauchant; Mitroff, 1992:15). The major difference is thus that crises rock the foundations of a system, and forces change, while disasters could certainly lead to change by bringing important factors to the forefront, but they don’t bear the same existential threat to the system.

2.10.1 Creeping crises

Environmental crises are often labeled as creeping, or slow-burning due to their gradual onset. As a result of their impact being hidden by scientific ambiguity these types of crises could take decades to manifest into undeniable accidents and disasters. (Boin; t'Hart, 2001:33).



		Speed of development	
		Fast: Instant	Slow: Creeping
Speed of termination	Fast: Abrupt	Fast-burning crisis	Cathartic crisis
	Slow: Gradual	Long-shadow crisis	Slow-burning crisis

Figure 4. A typology of crisis development and termination patterns (Boin; t'Hart, 2001:32).

2.10.2 Crisis from a functionalist perspective

Through a functionalist perspective one views societies and communities are structured based on maintaining essential societal functions. When disrupted by crises and disasters systems need to re-group by applying adaptative measures. Extraordinary events call for the use of remarkable resources and responses through adaptation (which could surpass the existing capacities of the system) to mitigate the impact on human lives, the environment, material wealth, and reputation (Engen, et al. 2017:267-268). Talcott Parsons (1951) argued that for any social system to maintain stability or complete developmental change in a stable way it is required to maintain a set of minimum functioning conditions. Thus, there are restrictions of a systems variability if it is to remain compatible with the conditions of its components, such as biological organisms, actors, personalities, cultural system (Parsons, 1951:27) In Pason's view there are four functional prerequisites for action systems: Goal attainment, Adaptation, integration and latent pattern maintenance. Thus, the ability to strive towards completing a common goal, the ability to adapt to the surrounding environment, the capacities to maintain and create cohesion and the distribution of meanings and values (Applerouth; Edles, 2016:359) It is also required that the parts of a system maintain adequate reinforcement from the other parts, thus maintaining cultural patterns that place a reasonable number of demands on actors and reward them for their accordance with these demands. Disruptive behavior is viewed by Parsons as an issue to the social system if such modes of action is arranged in sub-systems which diverge and affect the prerequisites for the social systems main functions (Parsons, 1951:27-28).

Parsons likely didn't predict that the goals of the global political order at the time of his writing would create the foundation for the contemporary conflict between our social systems technical abilities to achieve their goals, and the conditions of its components. Merton (1968) argued that: "Manifest functions are those objective consequences contributing to the adjustment or adaptation of the system which are intended and recognized by respondents in the system; Latent functions, correlatively, being those which are neither intended nor recognized." (Merton, 1968:105). Merton also categorizes three different kinds of unintended consequences. Some consequences are functional in relation to the system they are generated by; these are latent functions. Some are dysfunctional for the system; these are latent dysfunctions. The last type are consequences which don't affect the system either positively or negatively, these are latent non-functions (Merton, 1968:105). Considering the slow-burning climate-crisis we could view our global social system as actors and structures which comprise goals and abilities to adapt by processes of harmonization by use of social institutions (actor-structures) through homogenization (integration) and transmission of values and meaning (latent pattern meintainance) which facilitates action structures (Applerouth; Edles, 2016:359) (Parsons, 1951). The goals which are initially set may be important to maintain in order to keep the social system functioning. When challenges to these goals appear the social system provides solutions by adaptation which may at a later date become a fundamental part of the system's integration and latent pattern maintainance by use of social institutions.

2.10.3 Why unexpected events happen

The incubation period found in Turner (1978) is an example of how latent dysfunctions go unnoticed. Here, the accumulation of factors and conditions occur unnoticed because the normative prescriptions which align with the values present in the social system are at odds with the reality of the situation. The reason for such accumulation is directed at four origins: Erroneous assumptions due to beliefs and perception, issues in handling information during complex events, misunderstanding and/or ignorance of warnings, formal practices are not updated, or they are not followed (Turner, 1978:84-87). The increased vulnerability of the social system due to the accumulation of latent structures is thus related to a lack of attention (Engen, et al. 2017:266) in examination and/or knowledge of the contemporary state of the system. The problems may also in part arise as a result of the adaptation applied in order to achieve a goal. Hollnagel (2020) argues that there are inherent issues with attempting to fix problems in the ways in which we often do in the logic of contemporary organizations. Unexpected events which are set in motion by anthropogenic (man-made) latent functions associated with the activity of an organization (or multiple organizations), are usually handled according to a “find-and-fix” point of view. As a result, technological solutions are often deployed on top of another, which reduces the symptoms of problems short term, but in the long term leads to increased intractability of the system. (Hollnagel, 2020:8-9).

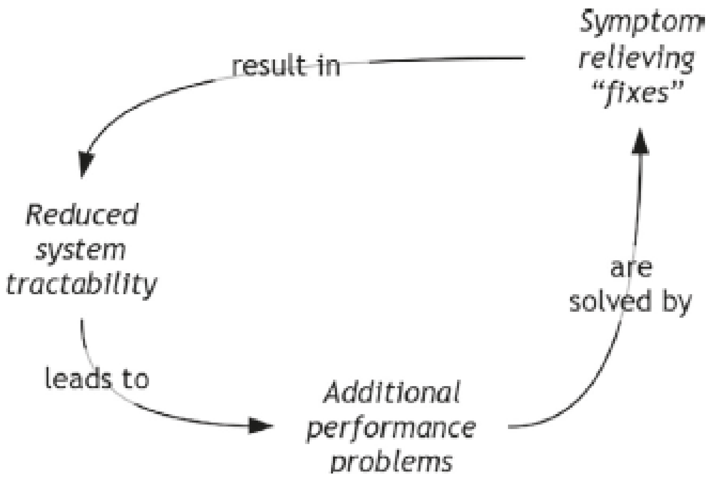


Figure 5.Symptom relieving fixes (Hollnagel, 2020:9)

Intractable systems are characterized by:

- Many parts and elaborate descriptions with many details. Principles of functioning are known for some parts but not for all.
- Changes are frequent and can be large.
- The system changes before descriptions are made.
- System parts and functions are mutually dependent and tightly coupled.
- Interdependence, high level of vertical and horizontal integration.
  (Hollnagel, 2020:8).

While Perrow (1984) focused on a similar proposition in his theory of Normal Accidents, the idea that accidents and disasters become more likely due to the combination of complexity and tight coupling in systems which only can be solved by reducing complexity and tight coupling (Perrow, 1984), Hollnagel's view of intractability differs slightly from Perrow's Normal accident perspective. Hollnagel is proposing that the notion of solving problems from a fragmented standpoint is the culprit of reduced opacity of the system. Fragmentation in areas of focus (such as separation in job roles such as quality and safety), fragmentation in scope (separation between parts, components, systems without holistic overview), and fragmentation in time (the perception of events only within a certain time window), are what leads to unexpected outcomes, decreased system opacity and an increase in emergent properties. The solution to this problem is to view systems in terms of functions, processes, changes and dynamics instead of perceiving them in terms of structures, outcomes, products and stability (Hollnagel, 2020:10,79-93).

From the standpoint of systems theory any description of a controlled process requires a higher level which applies constraints on the lower level(s). The information received in the higher levels of the control structure is less detailed, and thus gives the higher level a blurrier image of the functions in the lower level(s). The constraints imposed entail certain functions that are emergent, and these functions are not available in a detailed format to the higher levels of the control structure (Checkland, P, 1981:87). According to Leveson (2012) accidents come about due to dysfunctional interactions and troubles sustaining safety boundaries. Accidents are seen as the result of insufficient control structures, which the unintended event mirrors. In other words, accidents can be looked at as feedback loops which reveal areas of lack in control within a system. Such events allow for the diagnosis of gaps in safety boundaries, and to understand why and how the events happened (Leveson, 2012:67).

Thus, in order to maintain conditions which are compatible to the systems function one should view the system as a whole and utilize unanticipated events (latent dysfunctions) as important feedback mechanisms in order to re-organize the system's structure in a way which doesn't involve solutions that are based on a fragmented view of the system.

The word crisis has its roots in the proverb: "The change in the course of an illness" (Koselleck; Richter, 2006:360). A situation is often labeled a crisis when a pivotal moment appears, one in which our actions taken will mean life or death. When we choose to ignore the symptoms of the illness, or when we are assisted in patching over our ailments, instead of treating the underlying conditions or root cause of our illness we may be doing ourselves a disservice. "Prevention is better than cure" is often referred to in the context of emergency preparedness (Engen, et al. 2017:279). Just as how Renn (2008) and Hohenemser, et al. (1983) illustrate the steps of an action chain, we see here that the most preferrable strategy of risk reduction is to not let the conditions preceding the illness to appear in the first place. However, when the illness already has manifested and are shown to us through latent dysfunctions. We may wish to treat the symptoms in order to alleviate immediate pain, but the primary goal should be to understand and treat the root causes of the latent dysfunctions. However, this isn't always as easy as it may seem.

The concept of emergence establishes that the whole is not just the sum of its parts. The conventional method for examining cause and effect has been to divide the event into parts in order facilitate the explanation of the phenomena. However, we can't always find the causes by examining the effect. In other words, we cannot always rely on being able to find the conditions of an outcome by examining the outcome. Furthermore, we can't always predict the effects of a set of assumed conditions or causes either. Since we are usually conducting the examination within a certain time window, or with a certain job title, emergent effects might not reveal themselves from angle we're assessing. Thus, there is a lack of feedback, which impedes our ability to adapt. In addition, the concept of entanglement provides a description of severely intractable socio-technical systems, in that they have effects or outcomes which materialize seemingly without any connection to conditions or causes (Hollnagel, 2020:93). Leveson (2012) states that the concept of emergence dissipates the lower one goes in a hierarchy, in turn the lower one investigates a hierarchy the more associated complexity one will find (Leveson, 2012:63-64). When describing different levels in hierarchies there is a need for language designed to address that system. In order to describe the emergent properties which, come about due to the imposition of constraints (control) on the freedom on a sub-system, there is a need for language which goes beyond describing the parts comprising the sub-system (Checkland, 1981:81).

Since the lower one moves within a hierarchy, the more complexity is required in language to describe that level the connection to Weick (1999) is of use. Both the institutionalized diversity of knowledge and backgrounds within the staff, and enhanced awareness of the external environment and its possible future states enables organizations to maintain reliable operations (Weick et al., 1999:42, 44). Thus, they mitigate only utilizing self-referential language, but also looking outwards and using language which addresses different levels than their own. These kinds of structures address the fragmentation of the evaluation of the system (Hollnagel 2020) and attempts to mitigate the incubation of latent dysfunctions (Turner, 1978), by implementing the problem-solving dialectic by use of the standardization of inclusion of an increased variety in points of view, hence employing requisite variety or conceptual slack (Weick, 1999) (Schulman, 1993). However, Leveson (2009) states that the decentralization of decision-making during emergencies attributed to Weick (1999) assumes that the operator on the sharp end has system-level information available, which often isn't the case. To solve this the system would need to rely on effective standard procedures or on the decoupling of system components from the overall system to mitigate accidents (leveson, 2009:236-237). In other words, if there is both a lack of un-fragmented information available, and standard procedures can't solve the problem, there is a need for a variety in system components, parts or sub-systems which are decoupled in terms of common- cause and mode failures. This line of thinking is also in line with Reason's (2016) idea of defenses-in-depth by use of redundancy and diversity in order to achieve causal independence of failures. However, Reason states, just like Leveson (2012) the development of a system's redundancy and to ensure that there is causal independence, adequate feedback to inform design and development of a system is essential (Leveson, 2012:68). If accidents aren't reported, or ignored, the system's causal independence will be difficult to maintain (Reason, 2016:54-55), which can result in the incubation of disasters (Turner, 1978). However, when a crisis is of a creeping nature (Boin; t'Hart, 2001), feedback may be so fragmented in time that it is difficult to use it to inform design decisions.

2.11 Sustainability

Socio-technical system are inseparably connected to the outside world. Just as a plant is dependent upon water, soil and the sun, agricultural organizations are linked to larger scale socio-technical systems which are essential to understand in order to conceive how agricultural technologies such as vertical farming would affect the reliability of the system as a whole.

The library of Britannica defines sustainability as the long-term ability of a community, social institutions, or societal practice to continue its existence or current processes. Sustainability is coupled to the inherited moral actions where current environmental, social, and economic processes don't affect the abilities of later populations to continue the same processes (Meadowcroft, n.d.). Sustainability has in contemporary society in many ways entered our daily lives and values, while at the same time seeming like an immovable object to the individual person. A single person's ability to affect change is miniscule. However, the actions of groups of determined individuals have in the past created large transitions in different societies. Sustainability isn't just related to environmental impact, but rather a larger understanding of behavior which doesn't inhibit the ability of individuals over longer periods of time to exist, live meaningful lives or do they continue the same behavior in the future. Sustainability means to continue indefinitely, to maintain or support. The Latin root of this word is sustenere – meaning "to hold up" or "maintain." The most widely used definition of sustainability comes from the World Commission on Environment and Development (WCED), otherwise known as the Brundtland Commission (Jaqcues, 2021).

2.11.1 Lessons from the Brundtland commission

The Brundtland commission (1987) defined sustainable development as "Development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The central points of the Brundtland Commission, also known as the World Commission on Environment and Development (WCED) consist of defining sustainable development, the integration of economic and sustainable development, underpinning the reduction of poverty as a sustainable development goal, calling for cooperation in different sectors of society, the focus on inclusion of the general public and local communities in decision making. The commission notes that the effects of human activities were previously divided into silos in their respective nations and sectors, however the effects have started to spread across the borders of these silos, creating interconnected crises (Brundtland, 1987:13). The policies of independent nations, institutions and organizations can't efficiently solve these interconnected issues within their own silos. The need for a holistic approach instead of a fragmented one when solving environmental challenges is emphasized. However, there lies difficulty establishing this because organizations are generally compartmentalized by narrow tasks, channels of communication and decision making. The problems won't stop spreading beyond their previous borders, so in order to deal with the interconnection our institutions and organizations must change in order to solve them. Central agencies and ministries don't maintain strategies on how they will preserve the resource base their operations are based on (Brundtland, 1987:256-258). As a solution the commission recommends that we focus on the sources of environmental and social symptoms by ensuring that:

> Governments, of international organizations, and of major private sector institutions […] policies, programmes, and budgets encourage and support activities that are economically and ecologically sustainable both in the short and longer terms. They must be given a mandate to pursue their traditional goals in such a way that those goals are reinforced by a steady enhancement of the environmental resource base of their own national community and of the small planet we all share (Brundtland, 1987:258).

Furthermore, the commission states that mis-aligned focus by solving symptoms which are perceived as pressing through the use of technological development will provide immediate relief but could establish conditions and factors which manifest larger issues (Brundtland, 1987:42). To illustrate this the commission brings forth the agriculture sector as a relevant example:

> Settled agriculture, the diversion of watercourses, the extraction of minerals, the emission of heat and noxious gases into the atmosphere, commercial forests, and genetic manipulation are all examples or human intervention in natural systems during the course of development. Until recently, such interventions were small in scale and their impact limited. Today's interventions are more drastic in scale and impact, and more threatening to life-support systems both locally and globally. This need not happen. At a minimum, sustainable development must not endanger the natural systems that support life on Earth: the atmosphere, the waters, the soils, and the living beings (Brundtland, 1987:42).

2.12 The Multi-Level Perspective

The Multi-Level Perspective (MLP) was created by Ari Rip and Renѐ Kemp (Rip; Kemp, 1998). Later, the framework was polished by Frank Geels and Johan Schot (Geels, 2005) (Geels; Shot, 2007). The MLP is a useful framework for understanding sustainability transitions. The framework looks at the interplay among socio-technical regimes, niches, and the broader socio-technical landscapes. This theoretical framework attempts to map and explain how changes are set in motion by experiments due to innovation, and how these changes interact with more established socio-technical systems.

2.12.1 Socio-technical landscapes

Socio-technical landscapes are termed as the less fluid contours of our societies. Landscapes are not influenced purposefully by niches or regimes, but rather moved gradually by developments at the macro-level of society. The socio-technical landscape is shaped by factors such as: Globalization, environment, and culture. The landscape contains and guides the organization of spatial structures within society such as cities, infrastructure, production technologies, communication, and transportation. The functions of landscapes serve as a difficult to move structure which has significant influence on the conditions regimes and niches operate in (Geels, 2006:172).

2.12.2 Socio-technical regimes

Socio-technical regimes consist of an assortment of various actors, market forces, technologies, policy, science, culture, and industry which are established within our societal structure (Geels 2011:27). They refer to non-physical and fundamental ‘deep-structures’ which can be manifested as: “Engineering beliefs, heuristics, rules of thumb, routines, standardized ways of doing things, policy paradigms, visions, promises, social expectations and norms” (Geels, 2011:31). Within regimes social groups replicate a set of activities in which innovation or changes are generated in an incremental fashion, for this reason the make-up of the activities get ‘locked-in’. As a result the course of the ‘ship’ is viewed as ‘stable’ or ‘inert’ (Geels, 2011:27). Change within regimes are viewed as predictable, as if one is sailing on known waters and are familiar with the streams and wind conditions. Examples of these lock in mechanisms are:

“Shared beliefs that make actors blind for developments outside their scope, consumer lifestyles, regulations and laws that create market entry barriers, sunk investments in machines, people and infrastructure, resistance from vested interests, low costs because of economies of scale” (Geels, 2012:473).

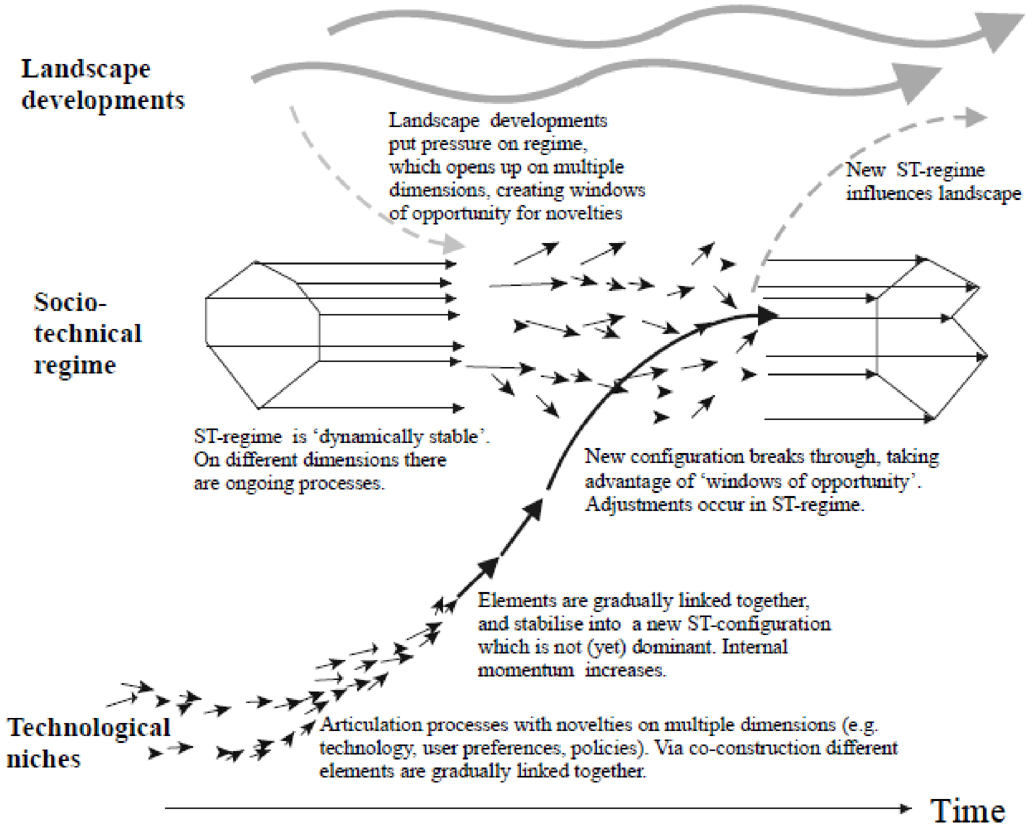


Figure 6 A dynamic multi-level perspective on system innovations (Geels, 2006:173).

2.12.3 Niches

Niches are spaces in which innovation occur in part with protection from outside forces. The processes which happen within niches are often established as a response to problems within the regime they are enveloped in. Actors within the niche underpin it with the aim of their work getting utilized within established regimes or to transform it completely (Geels, 2006:171-173). In order to accomplish this the actors, develop innovations that modify the tools, methods and results of existing regimes (Geels, 2011:27). A niche may often be exemplified by the misalignment or in some cases conflict with established regimes and may have trouble being adopted by the regime (Geels, 2006:173).

2.12.4 Sustainability transitions

In recent papers focused on looking at sustainability, we see that the term ‘Sustainability transitions’ often is utilized. Sustainability transition research in contrast with sustainability development-oriented research, is more focused on understanding the processes in which sustainable development is reliant upon and embedded in. The literature is not so focused on prescriptive problem-solution dynamics, but is rather studying the changes in the organizational, technological, socio-cultural, material, institutional, political and economic systems which facilitate sustainable development (Pisano, 2014:6-7). Sustainability transitions are goal-oriented and attempt to solve environmental issues, unlike many past transitions that were driven by the emergence of new technologies and commercial opportunities (Geels, 2011:25). Just like safety, sustainability is also an emergent property of a system. Sustainability should not be seen as something that is achieved by any individual part of the system. The broader view of the systems components, and their interactions between themselves and the outside world is important. Thus, the systems’ sustainability is both time and context dependent (Gaziulusoy, 2015:560).

Sustainable development is an ongoing process that seeks to improve economic, social, and environmental conditions for both current and future generations. It acknowledges change and goes beyond traditional planning and strategy-making. The focus of sustainable development should be on the process itself, not predetermined resources or institutions. This process relies on viability loops and adaptive capabilities. It works through perceiving and adapting to change. Much like the lessons from HROs, negative feedback is necessary to maintain balance in the process since these provide lessons for further development (Bagheri; Hjorth, 2007:94). When we start treading a path towards a goal with such processes it’s important that we maintain mindfulness of the consequences, or latent functions and dysfunctions which may arise from the processes themselves. Sustainability at a system level could, when certain negative feedback is not acknowledged, lead to issues in other avenues such as social justice. Therefore, the approaches which are utilized in sustainability transitions can cause exclusion and lead to economic stratification (Bennett, et al. 2019:2). Due to the collective nature of the goal of sustainability, private actors face difficulties when attempting to address sustainability transitions, due to the public authorities and civil society must play a major role to address public goods and internalize externalities, shift economic framework conditions, and support the growth of green niches (Geels, 2011:25).

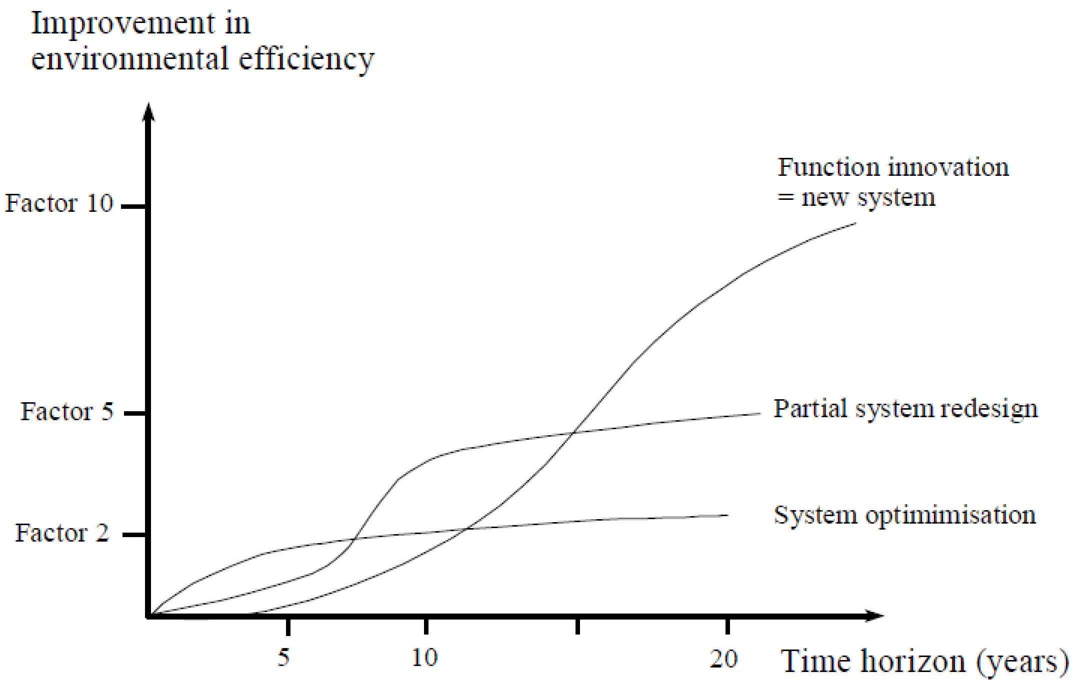


Figure 7 Environmental efficiency and system innovation (Weterings et al., 1997: 18)

Systems innovations are viewed by Geels (2006) and Elzen, et al. (2004) to possibly be the only way to enact large scale environmental efficiency improvements. Such innovations are associated with factor 10 improvements. While system optimizations and partial system redesign are associated with factor 2 and factor 5 improvements (Geels, 2006:164) (Elzen, et al., 2004:1) In order to implement system innovations there is a need for connecting several processes at multiple hierarchical levels through niches, regimes and landscapes. (Elzen, et al., 2004:11). In the findings and analysis and subsequent discussion chapter we will establish the factor improvements provided by CEA in light of our findings.

2.13 Conceptual framework

Utilizing the concepts and theories gathered above we can construct two approaches which can be fruitful when examining how the implementation of CEA may affect the reliability of agri-food systems. According to Hollnagel (2020) fragmentation and fixes introduced in a system with the intent of relieving symptoms in order to continue its goal attainment can increase the intractability of said system. The intractability in turn generates latent dysfunctions, which again need to be addressed. This causes a feedback loop of latent dysfunctions accumulating in different pathways that may or may not be within the systems boundaries (Hollnagel, 2020) (Turner, 1978).

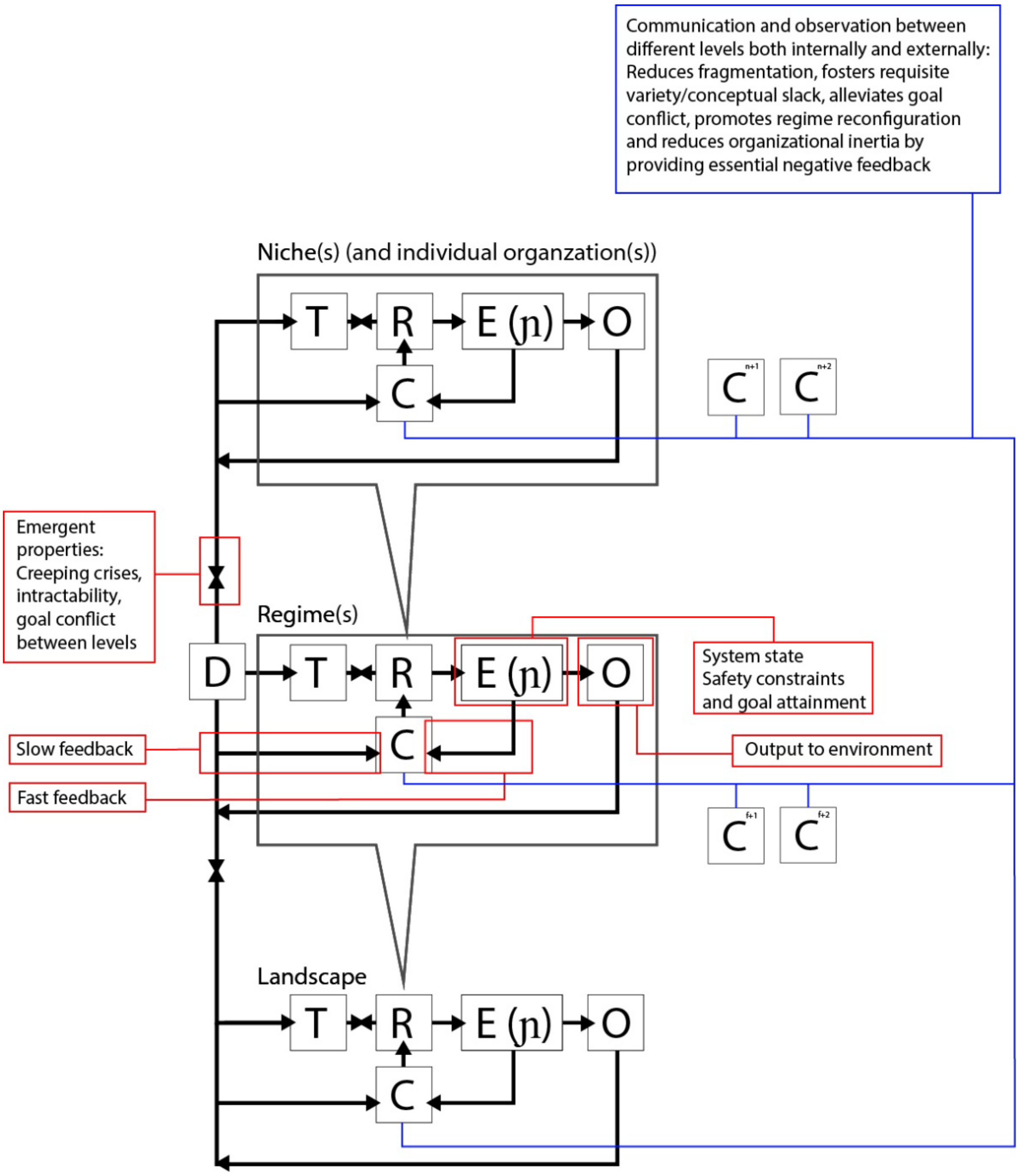


Figure 8 The conjunction of concepts and theories in a model

Utilizing the concepts and theories presented in the previous chapters we see that any system has inputs and outputs, or disturbances and outcomes (Ashby, 1956). Some of these outcomes are wanted by the controllers of the system, and thus form their goal attainment (Parsons,

1951) which is illustrated in figure 8 by (ɲ). We have chosen to separate outcome into both outcome and output. Thus, outcome signifies the short-term state of the system such as production capacities or internal operations, while output is the way the system affects the external world, which in turn feeds back to the system in combination with other system's output. Thus, variety in disturbances from the outside can be increased resulting from the output of a system. Unexpected events, or emergent properties can come about due to changes in output by other systems or one's own. When viewed according to the Multi-Level Perspective we can have multiple sub-systems inherent in one, depending on the resolution we are looking at it from. In figure 8 we see that niches are a part of the regulator of the regime and are thus subject to control actions taken by the regime's controller. While the regimes are subject to the control actions taken by the landscape. When referring to the controller in regimes and landscapes we are not referring to a single person, but rather to the interaction between several powerful social institutions and processes. For the regimes this might be the interaction between several large businesses in a sector and municipal, regional, and national governmental structures, while the disturbances which inform their action could be an amalgamation of market forces, technologies, policy, science, culture (Geels 2011:27). In terms of the landscape level the controller would be the interaction between national and supernational governmental structures and large transnational corporations that enact changes which facilitate large scale change such as globalization, culture and the environment by adjustments in infrastructure, cities, means of production, communication, and transportation (Geels, 2006:172).

Controllers adapt to their environment by use of control systems consisting of: Goal, model, sensors, actuators (Leveson, 2012) One could see creeping crisis such as climate change as a control problem. In my view of the conceptual and theoretical literature this control problem ultimately stems from fragmentation of knowledge (and language), time and spatial system boundaries by the compartmentalization of controllers at different hierarchical levels of sociotechnical systems (Leveson, 2012) (Hollnagel, 2020), which leads to issues related to the speed and capacity building of feedback and action structures. Organizations should be paying attention to processes beyond their boundaries in addition to maintaining and supporting variety within the organization in order to be able to uphold reliable operations and facilitate variety in order to assess and address problems from different angles (Weick; Sutcliffe, 1999) (Schulman, 1993). Leveson maintains that the design of the system should account for its safety constraints, thus being able to account for the variety which can come about from perturbations that lead to losses (Leveson, et al., 2009:238-239) (Leveson, 2012:267). We also see that smaller firms have the capacity for rapid innovation and adaptation as opposed to inert organizations (Vogus; Welbourne, 2003:878) (Brown; Eisenhardt, 1997:4-8). In figure. 8 we see that communication and observation between controllers, outside of their boundaries, and internally within the organization by observing the system's state is essential to change the design of the system to be able to maintain reliable operation in response to disturbances. In addition, in order to mitigate several failures many levels of the structure by the same causes the need for requisite variety in functional prerequisites is needed in order to inhibit common mode and common cause failures.

3 Methodology

In this section we will go over the paradigm, ontological and epistemological assumptions which guide the research. In addition, the research design, data collection, analysis and sampling methods will be made clear. Lastly the logic of inquiry and the process of inquiry will be expanded upon, followed by ethical considerations and the validity and reliability of the findings.

3.1 Paradigm, ontology and epistemology

The research paradigm utilized as a foundation for the assumptions of social reality am utilizing the contemporary social research paradigm of structuration theory by Anthony Giddens. A central ontological pre-supposition in this research is that the structures of which social systems, or socio-technical systems, are composed, and the agents operating within them are two sides of the same coin. They are a duality. Socio-technical systems are constantly reified by actors, and the actors' behaviors are instructed by the socio-technical system. The actor's behavior and the structure which informs their behavior are ontologically co-dependent, they influence and change each other (Giddens, 1987:62). Socio-technical systems may become more complex, unintelligible, difficult to operate as a result of solutions applied to short term symptomatic problems. "There is a range of circumstances which separate 'highly monitored' conditions of system reproduction from those involving a feedback of unintended consequences" (Giddens, 1987:69). This process could be seen through Giddens (1987) structuration theory as 'mixed intentionality', where a variety of actors by a mix of intentional and unintentional behavior generating feedback effects which become conditions for actors' behavior in the future (Giddens, 1987:11).

As such the ontological assumptions of the researcher can be categorized as depth realist. Social structures are not independent of the social actor, and they can be fragile as they depend upon commonly held beliefs, conceptions and relations. Social structures are considered as arrangements which are unobservable (Blaikie; Priest, 2019: 102), but their effects on the observer are very real, and can have immense impacts on natural structures.

The epistemological assumptions of the researcher are grounded in the neo-realism. If we wish to gain an understanding about the reasons why happenings, or events, occur we need to peer insight from the social and natural structures or mechanisms that enable them. In order to achieve insight into these structures and mechanisms there is a need to move beyond their apparent boundaries (Blaikie; Priest, 2019: 104). This view is congruent with the cybernetic and systems theoretic perception that similar kinds of mechanisms and structures are reproduced in all systems at varying levels of analysis.

3.2 Research design

In this paper an abductive approach has been utilized. The collection and in-part analysis of the empirical data has been conducted with an agnostic view of the theories which are applicable to understand and explain the phenomena we are attempting to understand. The reasoning for creating a conceptual framework from theory which is chosen over the course of the literature review is since the topic of this paper is a rather new phenomenon. The goal was to find safety related theoretical frameworks which allow for the ability to effectively explain the phenomena I am studying. I didn’t want to try to fit our empirical data to a predetermined theoretical framework. Also, a purely inductive approach which explains what vertical farming is, was thought to be lacking in the capacity of analysis of this phenomenon through the lens of safety. Therefore, I chose to analyze the literature, create a conceptual framework which could give us an effective lens for analysis of the phenomena, and then further view the empirical data through that lens.

This study employs a mixed methods research approach to investigate the characteristics, perceptions and motivations of the strategically selected interview sample. Furthermore, the research has found and compared data practices, to statistics and information gathered by means of a document review regarding the structure, functions and risks of the Norwegian agri-food system in order to understand the control structure and vulnerabilities which can impact its reliability. By combining quantitative data on resource consumption with qualitative insights on motivations, areas of risk, and perceptions on the potential impact of CEA systems, a comprehensive understanding of the research problem is achieved.

3.3 Quantitative data collection and analysis

The quantitative data was gathered in conjunction with the semi-structured interviews from two of the interview respondents, as they were the only respondents that were involved with currently operating CEA systems. Questions regarding amount of electricity used, amount of water used, and amount of yield produced were asked. Then the findings were extrapolated and compared to data retrieved from the document analysis.

The collected quantitative data from the interviews was contextualized using data gathered from document review of statistics. This process consisted of analyzing different statistics about GHA production in Norway. Resource input data was gathered from Statistics Norway (SSB). This collection concerned the same types of data gathered from respondents such as electricity use, yield produced, and square meters used. Furthermore, data which was lacking, particularly in terms of water use was supplemented with research papers gathered in the literature review. Data concerning the GHG emissions associated with the Norwegian energy grid were gathered from The Norwegian Water Resources and Energy Directorate (NVE), this process was also supplemented with a variety of sources which had published data on the CO2 emissions from different heating fuels used in GHA production. Thus, comparisons were made between the respondent's system's resource consumption and Norwegian national averages to identify deviations or significant differences.

Qualitative data collection and analysis

To capture qualitative insights, in-depth interviews were conducted with respondents. The interviews focused on exploring motivations behind resource consumption, areas of risk related to energy and water usage, and respondents' perception of their future influence in sustainable practices. Open-ended questions were used to encourage respondents to express their thoughts, experiences, and perspectives freely.

The qualitative data obtained from the interviews were transcribed verbatim and analyzed using thematic analysis. Themes and patterns related to motivations, risk perceptions, and future influence were identified through a systematic process of coding and categorization. The interviews gave direction to the document analysis which provided further insight and context.

The document review concerned a mix of qualitative and quantitative data from reports, official documents and websites which served to establish an environmental assessment of agricultural systems. Furthermore, document review of reports, official documents, case studies and Norwegian laws were analyzed to provide an understanding of the structure, functions and risks to the Norwegian agri-food system.

The qualitative findings were then integrated with the quantitative results to provide a comprehensive understanding of the research topic.

3.4 Integration of Quantitative and Qualitative Findings

The integration of the quantitative and qualitative data was conducted through a process of triangulation. The quantitative findings provided numerical evidence on resource consumption, while the qualitative insights added depth and context to the understanding of respondents' behaviors and perceptions. This mixed methods approach allowed for a comprehensive analysis and interpretation of the data, offering a more nuanced understanding of the characteristics, motivations, and perceptions of the selected sample regarding the internal and external reliability, sustainability and control structures of CEA practices compared to GHA and OFA.

3.5 Sampling of data for document analysis in literature review and document review

List of keywords used in gathering articles, reviews and case studies for the literature review:

Vertical Farming, Food safety, Food security, Requisite variety, Reliability, High Reliability Organizations, Resilience, Climate Change and Agriculture, Conventional Vegetable Agriculture, Multi-Level Perspective, Crisis.

Databases which have been utilized to gather literature include Google Scholar, ELSEVIER/ScienceDirect, ResearchGate, Oria, JSTOR. The sources used have been chosen strategically based on criteria's such as relevance of themes, relevance to research topic. relevance to framework, relevance to theory, relevance to methodology. In addition, the research cited has been assessed on their number of citations of publication, h-index of author and i-10 index of author.

The weight of the citations, h-index and i-10 index have been adjusted based on the relevance and date of publishing of the associated literature. If the literature is highly relevant to the research problem there has been focused less on the importance of citations, h-index and i-10 index. In particular, research linking vertical farming and food safety and security generally have a lower citation, h-index and i-10 index score than literature which is focused on climate change, agriculture, conventional vegetable agriculture, food safety and security and the Multi-Level Perspective.

The literature review was conducted by looking at several different research papers, case studies, reports and literature reviews of relevance to the topics of: Vertical farming, Controlled Environment Agriculture, urban agriculture, sustainable agriculture, logistics and supply chains, as well as reports on climate change's effect on agriculture and reports on Norway's agriculture system.

Codes looked for include:

- Reliability, resilience, redundancy, food safety, food security
- Water use, irrigation
- Fertilizers, nitrogen release, nitrogen consumption/use, nitrogen/phosphorous runoff, erosion
- Pesticides, herbicides, chemical runoff
- Ecosystems, biodiversity
- GHG impact, warming impact, climate effect, anthropic emissions
- Yield, efficiency, productivity, quality
- Land use, production area, yield
- Transport, transport emissions, supply chain risk, logistics risk, complexity
- Agricultural history, industrialization, globalization, innovation

Reports, official documents, and research papers from the literature review were also utilized in the document review in order to establish the environmental assessment of agri-food systems. In terms of data on Norwegian agriculture the research has mostly been accessed from channels such as the Norewegian ministry of agriculture (Landbruksdirektoratet), Nibio, JOVA, NVE and SSB. During the analysis certain points of gaps in knowledge which are attempted to be closed have involved utilizing case studies gathered from the literature review and wider web searches by utilizing Google's search engine. These instances are applicable to energy conversions to CO2 and understanding the structure of the Norwegian agricultural system.

Two different qualitative thematic analyses have been conducted by use of NVivo software. The analysis of the interview transcriptions from the respondents were coded into:

Motivations

- Experience
- Geographic conditions
- Positive impact

Production method

- Aquaponics
- Hydroponics
- Aeroponics
- Closed-loop water system
- Sensors

Regime interactions

Internal reliability

- Safety measures/constraints

External reliability

- Contribution to/impact on agri-food system reliability

Sustainability

- Fertilizers
- Pesticides
- Transport
- Water use

3.6 The abductive research process

While induction generally are arguments which take a body of data and attempt to generalize them over a wider range of happenings. In abductive research one takes a selection of data and attempts to form an explanatory hypothesis based on the data (Burks, 1946:301). At the onset of this paper, the objective for this research was at first to understand vertical farming, which was broadened to CEA in general, through the lens of societal safety literature. Research literature and case-studies on the topic of CEA commonly suggested that CEA could contribute to improvements in food safety and security. However, none of these papers appropriated their analysis toward matching safety, security or reliability theory toward understanding and explaining the characteristics of CEA. From figure 10 the research's point of prior theoretical knowledge (0) and the discovery of deviating real-life observations (1) were established before the research was started. The prior theoretical knowledge here lies in: Conventional vegetable agriculture (OFA and GH) are the most utilized methods of farming, and thus the most reliable production nodes in agri-food systems. The adoption of CEA itself is thus viewed as a deviation from commonly held perspectives on agri-food systems, that there are other farming methods which may be more suitable farming methods as production nodes in agri-food systems. The research process started with theory matching (2), where it was found that the multi-Level perspective was a rather excellent theory to explain how such small niches manifest and how they affect and are affected by broader systems. After the first interview with respondent 3, it was found that some HRO terms could be utilized to explain the characteristics of CEA. After the interview with respondent 4 the conceptual framework was reworked to include crisis, sustainability and latent dysfunction. After the interview with respondent 1 it was found that system theoretic process assessment could be better utilized to compare safety and reliability characteristics in the different farming methods (OFA, GH, CEA). In addition, requisite variety, conceptual slack and resource slack were found to be the most relevant concepts from HRO literature to the research topic. After the interview with respondent 2 the idea to compare the safety constraints of OFA, GH and CEA visually was found to be an ideal way to present the differences between.

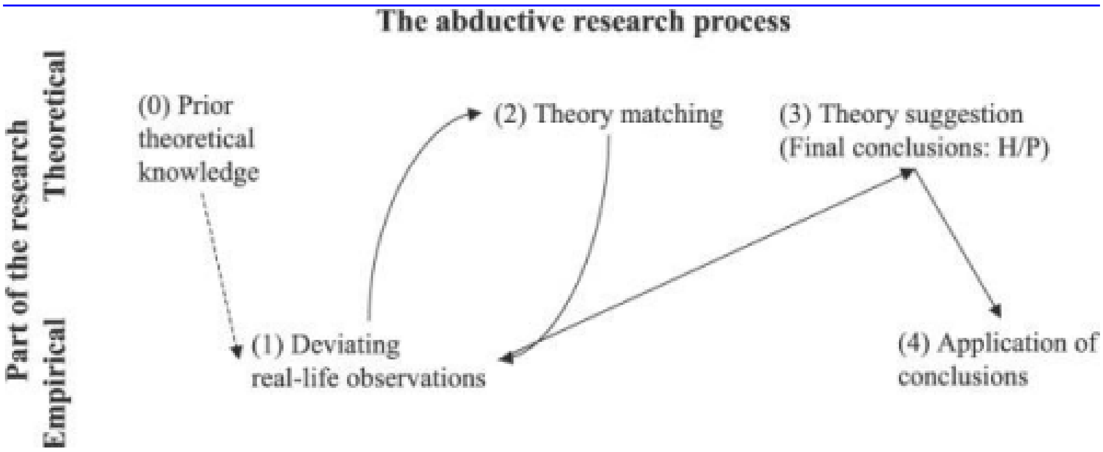


Figure 9 Abductive reasoning (Kovács; Spens, 2005)

Furthermore, a cybernetic viewpoint was found to envelop several relevant theoretical and empirical research findings, such as the law of requisite variety, and systems theory perspectives from Leveson (2004) (2009) (2012). Thus, from the onset where this might have been an inductive research design, attempting to generalize findings onto a larger system. I have instead come to construct a hypothesis based on the research process. This hypothesis is laid out in chapter X. The abductive logic is used to seek out reasons, rather than causes, attempting to understand the world which is experienced by certain actors in their context (Blaikie, 2019:99).

With my background in sociology, I was intrigued by the connections between relevant literature to the research topic and both sociological and societal safety perspectives. There seemed to be similarities and consistencies between much of the theory found to be relevant to the research topic, as if they were pointing to parts of the same mechanism. These include the connection between latent dysfunctions, landscape factors, intractability and themes in the Brundtland commission to the actions and motivations of CEA-actors. I wished to develop a hypothetical model which could aid the explanation and understanding of the causal mechanisms which propagate feedback loops of intractability and latent dysfunction, for this task retroductive logic has been utilized. Furthermore, the analysis of the control structures in OFA, GH and CEA, and the STPA analysis of the Norwegian agri-food system have also followed a retroductive logic. In combination these logics of inquiry are used in an attempt to gather a holistic understanding of the research topic. Retroductive logic is used to find structures which can explain regularities in certain social contexts. Thus, our findings from our conceptual framework, literature review and interviews are combined into different models which attempt to explain the structures which produce the phenomena I'm interested in studying. Namely, why does climate change affect agri-food systems? Why do agri-food systems contribute to climate change? Why does landscape, and agricultural regime factors influence the emergence of CEA in Norway? What impact could CEA have on the reliability of agri-food systems?

The structure of the thesis is presented in conjunction with the rule, result, case structure of abductive research logic (Bellucci; Pietarinen, n.d.). First the literature review and conceptual framework which lay out the first principles (rules); which in this thesis are the elements within the literature review and conceptual framework previously presented. The conclusion (result); this is the data gathered from the interview process and document review. And lastly the hypothesis (case); which is the conclusions arrived at inferred from the data viewed in light of the conceptual framework.

The collection and in-part analysis of the empirical data has been conducted with an agnostic view of the theories which are applicable to understand and explain the phenomena I am attempting to understand. The reasoning for creating a conceptual framework from theory which is chosen over the course of the literature review is since the topic of this paper is a rather new phenomenon. The goal was to find safety related theoretical frameworks which allow for the ability to effectively explain the phenomena I am studying. Therefore, I chose to analyze the literature, create a conceptual framework which could give us an effective lens for analysis of the phenomena, and then further view the empirical data through that lens.

3.7 Selection of interview respondents

I have chosen to conduct a strategic selection. There has been a conscious choice to select interview respondents of relevance to the research topic. The reason for conducting a strategic selection of interview respondents is because CEA is not something most individuals have knowledge about. There is a limited selection of actors which are involved in or operate CEA organizations. Therefore, there has both been conducted an outreach to Norwegian and international businesses involved in CEA via e-mail. One respondent was discovered by snowball sampling, and the rest have been discovered in strategic outreach by use of Google's search engine to relevant companies and actors by e-mail. In qualitative research it is important that the selection is purposeful and that the interview respondents can shed light on the problem topic and questions. In qualitative research the relevance of the selection of respondents is more important than the number of respondents (Johannessen; Tufte, 2002: 90). The interviews were conducted with four persons involved in CEA organizations. The table below provides specific characteristics about the respondents.

Interview (n)	Operational phase	Their relationship to CEA	Location
1	Operational, in production.	CEO of a company manufacturing modular hydroponic vertical farming CEA systems.	Norway.
2	Start-up, R&D.	Project manager of a company in the planning process of constructing a circular, closed environment, aquaponic CEA system.	Norway.
3	Operational, in production.	CEO of a company producing vegetables mainly for hotels and restaurants using hydroponic vertical farming systems located in a greenhouse.	Spain.
4	Start-up, R&D.	CEO of a company focused on research and development of vertical farming equipment and components.	USA, California

3.8 Interview execution

The choice was made to conduct semi-structured interview. This method is the most widespread form of qualitative interviews according to Johannesen & Tufte (2002). Semi-structured interviews combine questions based on an interview guide with general questions about specific topics and themes relevant to the research, but that also allow for discussion and exploration of the themes between the interview respondent and the researcher (Johannessen; Tufte, 2002:102). This enables unprepared follow-up questions to relevant aspects of the interview to occur. The interview guide was also prepared differently for each respondent based on background information about the respondents and their areas of expertise. The interview guides are located within the appendix of the paper.

All interviews were conducted by video calls. Additional information was also provided over e-mail from some of the respondents to follow-up questions that arrived later in the research process. The first two interviews conducted, with respondent 3 and 4, were more focused on the actors' motivations and their technical knowledge about CEA systems. After a process of theory matching, the interviews with respondents 1 and 2 were conducted. Here, the interview process was oriented around the actors perceived impact of CEA on agri-food systems (which served to better enlighten their motivations) and their technical reasoning for building their systems a specific way. The interviews with respondents 1 and 2 included a ranking process of the potential impact of CEA compared to OFA, which naturally evolved during the interviews to also include comparisons to GHA as well. The actors' perceptions of the impact of CEA on agri-food systems also serves as relevant data from an abductive standpoint due to its focus on arriving at the best possible explanation based on an incomplete set of data. This approach allowed guidance for the document review analysis into the most relevant areas of consideration. In particular, the analysis of landscape and regime influences on CEA and its development in Norway required direction achieved from the interviews with respondents 1 and 2.

3.9 Ethics

Ethics are described as rules, guidelines and principles concerning the assessment of actions which are right and wrong. Ethics is also concerned with the relations between people, and what we should and should not do to one another (Johannessen; Tufte, 2002:65). When we are gathering information about people there are many ethical considerations that must be assessed. In using a qualitative method, we are receiving information directly from people. This necessitates the need for respect, care, and discretion. All the respondents have signed a privacy consent form (cf. Appendix) and have been allowed the choice to withdraw their information from the research process at any point up-until delivery. The choice was made to anonymize the names and workplaces of the respondents, even though the privacy consent form gave permission to include this information. Leaving this information out of the paper was decided on due to privacy considerations and deliberation with my supervisor. However, their geographic location is considered particularly relevant to the research so this information has not been anonymized. Geographic location is also not considered information which can identify an individual, however due to the small number of organizations enveloped in CEA practices the choice was made to not specify geographic location further than the country of the respondents. There are certain ethical considerations which are relevant to deliberate on in terms of the purpose of the research from the perspectives of the respondents. When the respondents during the interview process have the impression and the expectation to have their names and workplaces included in the published research. Thus, improvements in future research ethics should involve a concrete decision on anonymization before the interview process starts and clear communication about this decision to the respondents in order to minimize the deviation in the respondents' expectations of the research from the final result (Silverman, 2014:146).

The privacy consent form was created during the beginning of the research and therefore contained slightly different research questions than the final paper. As a note to improvements in future research the privacy consent form should have been updated with the most current research questions at that point in time and should also have been formatted in the Norwegian language to the Norwegian respondents. While the Norwegian respondents of course are highly competent adults that are well versed in the English language, it would have provided an even better guarantee for the respondents understanding of the contents.

The conscious choice was made to not utilize audio recordings, as the privacy concerns outweighed the relevance to the nature of the data sought after. However, there are issues with written transcriptions, as it is easier to make mistakes during the interview, and to misrepresent data. Fortunately, as noted before, the respondents were more than willing to answer any follow-up questions concerning the data collected. The respondents were also sent a final draft of the interview sections before delivery of the paper. The data was collected by use of transcription to documents in Microsoft word. The transcription files were always located within an external encrypted hard drive, also during the initial transcription process during the interviews. Naturally there are ethical considerations associated with video calls. The video calls were conducted through Microsoft Teams. None of the video calls were recorded in any way except by written transcript. The interview respondents made the choice on their own if they wanted to leave their camera on or off during the interview process.

3.9.1 Validity and reliability

Validity concerns the relevance of the data in relation to the phenomena which is studied (Johannessen; Tufte, 2002:53). Since the interview respondents are individuals with knowledge on various CEA systems their selection has been made with validity in mind. The abductive research method has been chosen due to the nature of the data collected. As the research problem is concerned with future developments and the impact of technology on a larger system, the conclusions made based on this paper cannot be considered as valid inferences, as they are not deductive inferences based on premises. Instead, the abductive inferences made may be viewed as the best explanations based on the dataset analyzed (Douven, 2021). The goal of this paper is to spur the creation of hypotheses which may be included in inductive and deductive research at a later date. Since validity is concerned with the appropriateness of the methods utilized when attempting to answer the research questions (Leung, 2015), it is important to address the thought process behind the development and design of the research. The research design is of an abductive form, and therefore the process of generating the research problem have gone through several iterations based on their applicability toward the data. Due to the limited access to data on the phenomena studied, the research process has been adjusted in order to generate "the best explanations" based on the available dataset.

Reliability concerns the accuracy, generalizability and replicability of the data collected. The quantitative data has as mentioned been gathered by means of document review from reports, official documents, case studies and legal documents while the rest has been gathered from the interview respondents. The accuracy of the data gathered from document review would mostly be subject to questions of reliability in terms of mathematical errors. The mathematical reasoning is provided within the findings and analysis. There has been conducted a process of triangulation of the quantitative results from the interview respondents with findings of research papers analyzed from the literature- and document reviews. Since parts of the data has been gathered through qualitative interviews, one could argue that there is limited replicability of the data. This is because the researcher is the instrument which gathers the data by asking specific questions to a specific selection within a specific context. No two researchers are the same, and therefore a different researcher might find different answers. There are disagreements between qualitative researchers about the ability to corroborate and replicate unique accounts from qualitative research at all. However, what may be especially for the reliability of qualitative research is the explanation of how it has been conducted, and the corroboration and agreement from the interview respondents on the researchers accounts of their conversations (Blaikie; Priest, 2019:211). The interview respondents have all agreed to the accounts of the data concerning them in this paper, and I hope that the methodological chapter has made big enough strides toward providing transparency about the research process.

4 Findings and analysis

The findings of the literature review and the qualitative interviews is presented in the following chapter. The structure of the findings is divided into the following sections.

4.1 Document review

The following sections are laid out in a top-down structure based on the Multi-Level Perspective framework by Geels (2011) (2004) (2006) and Elzen, et al. (2004) by elaborating on the landscape, with reports concerning the state of global agriculture, and on the regime with reports and documents concerning its structure, functions and vulnerabilities. The first section concerns the findings from the review of official reports by institutions such as FAO and the IPCC in order to establish the reasons for the existence of vulnerabilities in contemporary agriculture due to environmental pressures and effects of agriculture. The following section provides reports, publications and data from institutions such as the Norwegian ministry of agriculture and food, the Norwegian government, Nibio and JOVA to establish the context, structure and policies of the Norwegian agri-food regime.

4.1.1 Environmental pressures on and effects of agriculture

In order to illustrate the problems that the agricultural system in the world faces today I should illuminate the situation with a quote from the director general of the Food and Agriculture Organization Dr. QU Dongyu, which is contained in the foreword of the recently released *the state of the world's land and water resources for food and agriculture report* by the FAO.

> The pressures on land and water ecosystems are now intense, and many are stressed to a critical point. Against this background, it is clear our future food security will depend on safeguarding our land, soil and water resources. The growing demand for agrifood products requires us to look for innovative ways to achieve the Sustainable Development Goals, under a changing climate and loss of biodiversity. We must not underestimate the scale and complexity of this challenge. The report argues that this will depend on how well we manage the risks to the quality of our land and water ecosystems, how we blend innovative technical and institutional solutions to meet local circumstances, and above all, how we can focus on better systems of land and water governance. (FAO, 2021:VII)

The 2021 SOLAW report provides a comprehensive analysis of the current state of global land and water resources for food and agriculture. It highlights several critical issues and findings that must be addressed to ensure sustainable management and use of these resources. One of the key issues highlighted in the report is soil degradation, which is affecting the productivity of soil and reducing its ability to provide ecosystem services. This degradation is due to a combination of human activities and natural factors. Another issue is land degradation, which affects one-third of the world's land area and has a significant impact on the livelihoods of millions of people. (FAO, 2021:10) The report also highlights the challenges posed by water scarcity, which is affecting agriculture, food production, and food security, particularly in arid and semi-arid regions.

Climate change is a critical issue, as it is affecting the availability and quality of land and water resources for food and agriculture and increasing the risks and uncertainties associated with food security. In addition there are anthropogenic drivers caused by agricultural methods which intensify the use of land that cause externalities which spread to different sectors and environments, leading to the pollution of groundwater, surface water and causing land degradation (FAO, 2021:XI). The cultivation of crops and animal husbandry takes up roughly 38% of the world's land area, of which 33% is affected by anthropogenic degradation. Agriculture also consumes 70% of global freshwater withdrawals (FAO, 2021: xi, 2, 10). In multiple countries across the globe agriculture is the biggest source of water pollution. Only 44% of the water utilized for agricultural purposes by irrigation is absorbed by plants through evapotranspiration. The remaining 56% is released into the water table or is absorbed into rivers and oceans. Nitrogen is the largest chemical contaminant in the world's groundwater (Mateo-Sagasta, 2018:4). 38 percent of the bodies of water located in the EU are significantly affected by pollution due to agricultural practices (Connor, 2015:71).

4.1.2 Increasing frequency of weather-related disasters

Climate change induced environmental crises is an important factor to consider when we are attempting to understand disruptions in agriculture. Since farming systems are vulnerable to natural disasters; crop growth, livestock health, fisheries and forestry are all brittle in terms of drastic change to environmental change (Markova, et al., 2018:4). We can see that the economic loss due to disasters in developing countries is rather telling about the increasing frequency of destructive weather-related phenomena (Markova, et al., 2018:4). A review of 74 Post Disaster Needs Assessments established in 53 developing countries between 2006 and 2016 showed that the agricultural sector was subject to: "23 percent of all damage and loss caused by medium- to largescale natural disasters. When only climate-related disasters (floods, drought, tropical storms) are considered, the share of damage and loss absorbed by agriculture increases to 26 percent.” (Markova, et al., 2018:16).

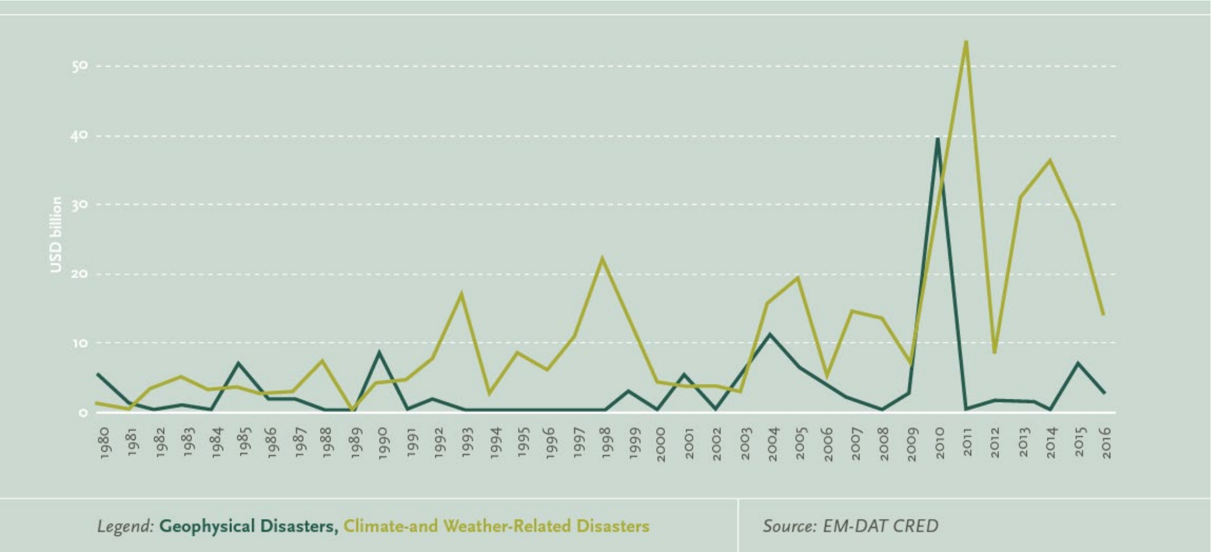


Figure 10. Economic loss from disasters in developing countries 1980-2016 (FAO, 2017:16).

The SOLAW report highlights the impact of biodiversity loss on the provision of ecosystem services and the resilience of food and agriculture systems to climate change. The report also mentions that the COVID-19 pandemic has exposed vulnerabilities in global supply chains which are still playing out and need to be a priority for investments in the future in order to mitigate risks of supply chain failure (FAO, 2021:56).

4.1.3 Transportation and GHG emissions

Agricultural practices today represent 23% of global greenhouse gas (GHG) emissions (IPCC 2019). While a lot of this stems from grazing, fertilizer production alone is estimated to generate 1.2 % of all anthropic GHG emissions. A lot of energy goes into creating fertilizer, while it also releases significant amounts of nitrous oxide. Nitrogen fertilizer production alone uses about 5% of global natural gas supplies (Woods, et al. 2010). 7.3 energy units (consisting mainly of fossil fuel) was estimated in the turn of the century to be used in the US food system to produce 1 food energy unit. It was estimated that about 10% of US energy consumption was used within the food system on a yearly basis (Heller; Keoleian 2000:42), within these 10% the processing, packaging, transportation, storing and preparation of food was estimated to consume about 80% of energy production in the food system (Heller; Keoleian, 2000:41). Contemporary literature on GHG emissions of food systems conducted by Li, et al. (2022) estimate that global food transportation contributes to about 3.0Gt of CO2 equivalents, or 19% of all greenhouse gas emissions in the food system when including land-use change, and 30% of all GHG emissions when excluding land-use change. The largest contribution to GHG emissions in production systems is meat, which contributes to 39% of all food production emissions, while the production of vegetables and fruits contribute about 6%. However, when it comes to global food transport, vegetables and fruits contribute a striking 36% of global food-miles emissions, where the transport of meat only contributes 4%. The overall trend is that meat production overall contributes to more GHG emissions but is usually traded internally within a nation rather than being imported and exported. Whereas vegetables and fruits are often imported and exported (Li, et al. 2022:446-450). In 2021 the International Energy Agency reported that global GHG emissions were 36,3Gt of CO2 and CO2 equivalents (IEA, 2022:3). Thus, considering the findings of Li, et al. (2022) in conjunction with the IEA emission data we see that food miles are estimated to be the source of 8,26% of global GHG-emissions. Furthermore, 2.97% of global GHG emissions can be attributed solely to the transport of vegetables and fruits, while the transport of meat is the source of 0.33% of global GHG emissions. Total food production cause roughly 19,5% of global GHG emissions. Meat production is responsible for 7,6% of all global GHG emissions, while vegetable and fruit production are attributed to 1,17% of global GHG emissions. The vegetable and fruit supply chain are in total responsible for 4,14% of global GHG emissions. While the meat supply chain is responsible for 7,93% of global GHG emissions.

Heller & Keoleian (2000) underlines that the dependence on fossil fuel energy to produce food facilitates a high degree of vulnerability within food systems. Since petroleum fuel prices rely on the continued production of a finite resource supply shocks can have rather significant consequences on the prices of food products. When farms, production, processing, packaging and distribution facilities are consolidated the distance between consumer and source becomes greater, and thus we need more energy to store and transport food (Heller; Keoleian, 2000:42). In terms of the agri-food system the availability of ‘global cool chains’ (the ability to utilize food freezing technology during international transport) has allowed us to enjoy foods that come from geographies which are very distant to our own. Since the beginning of the globalization trend in modern history we have seen a shift from local food production to the rise of large-scale imports and exports between countries. Food production has remained a local process which is directly connected to soil, climatic and socio-cultural processes. Food production as a globalized phenomenon causes large environmental changes as it is directly connected to natural ecosystems (Dicken, 2014:424, 425). Farmers often treat products with chlorine compounds or antioxidants which serve to enhance preservation during and after washing. Vegetables are usually packaged and stored in refrigerators in order to expand product life. However, OFA producers are not able to perform refrigeration between harvest and transport to processing facilities. This contributes to uncertainty of pathogens in the vegetables. Groceries require on average 2000 to 3500km of travel, or 4–6 days in transit before arriving in grocery stores, and every three days after being harvested the products lose about 30% of their nutritional content (Avgoustaki; Xydis, 2020:35).

4.1.4 Supply chains

The supply chain and logistics are large risk factors for food in the modern world due to the globalization of the world's food production. Increased complexity of supply chains have been steadily growing along with the industrialization of food production. The probability of supply chain and logistics risk events increases because of outsourcing. When a countries food suppliers become dependent on production which is outsourced the uncertainty of the supply chain increases (Diabat, 2012:3039). The risks exposed to supply chains can be characterized as macro-level external disruptions such as natural disasters and political tensions, changes in consumption patterns, resource shortages, communication failures, overstock and understock issues, forecasting and IT systems failures (Diabat, 2012:3043). Yang et al. (2010) looked at how Perrow's (1984) normal accident theory can be utilized to understand supply chain risk from a complexity perspective. The paper concludes that natural accident theory supports the notion that supply chain agents could avoid supply chain disruptions if they reduce interactive complexity and tight coupling. Simplification of their systems is encouraged in situations where economical survivability is threatened by the reduction of interactive complexity and tight coupling. Since the market today is largely driven by time-sensitive consumption cycles the supply chain and sales industries have adapted by developing strategies which enable responsiveness to consumer demands by storing less inventory and shipping at lower cost (Yang et al., 2010:1906) Yang et al. notes that:

> These strategies help avoid the risk of stock obsolescence or stock out inherent in the current business trends of expanding product variety, rapid technological development, shortening product life cycles and increasingly demanding customers. However, this could also lead supply chains to become more vulnerable to disruptions. With just-in-time production, for example, there often tends to be very little inventory existing to

> hedge against potential disruptions in supply. Therefore, the supply chain literature supports the notion that there is a positive relationship between tight coupling and the likelihood of experiencing a supply chain disruption. (Yang, et al., 2010:1907)

4.2 The Norwegian Agricultural Regime

In 2018 Norway saw one of the harshest summers recorded in terms of agricultural conditions. It was the fourth driest summer ever recorded in Norway (Stolt-Nielsen, 2019). By the end of 2018 almost 15 000 applications for crop damage compensation had been filed to the ministry of agriculture and food in Norway. The total payout to affected farmers was 1,6 billion NOK (Landbruksdirektoratet, 2019:12), 13 460 of the applicants were accepted for crop damage compensation as of july, 2019 (Bondelaget). Considering that in 2018 there were 39 678 agricultural companies in total in Norway, this means that about 34% of all agricultural production in Norway had crop failure by at least 30% or more of their average yield (Landbruksdirektoratet, 2022). The directorate for societal safety and emergency preparedness published a report a year prior to the drought which gave an overview of the estimated likelihood and controllability of the risks present in Norwegian agriculture.

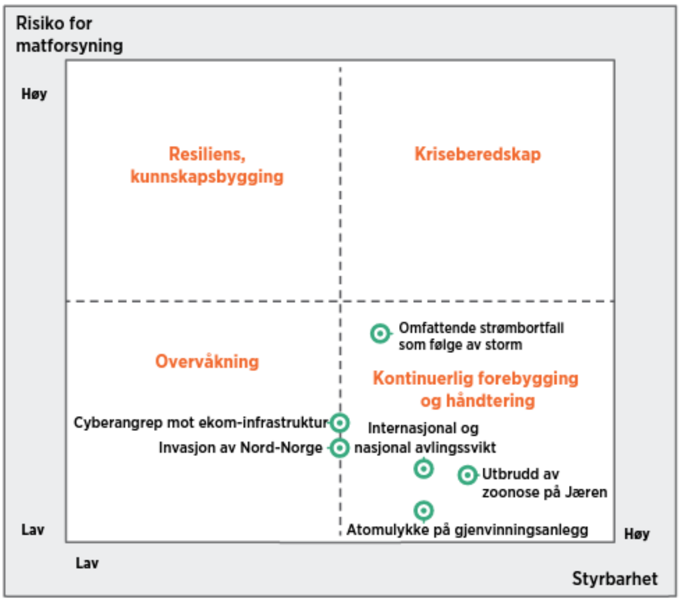


Figure 11 The risks of the agri-food systems and their governability (DSB, 2017:104)

The analysis afforded certain problems repeated iterations of relevance. The prioritized problem areas recommended by DSB thus consisted of:

- "Securing distribution and access to food all the way to up to consumption.
- Food supply dependency on other critical societal functions.
- Dependency on food imports.
- Complex events which demand great resources and multilateral cooperation."

(DSB, 2017:104)

In figure 12. the highest risk to food supply is deemed to be a large-scale loss of power due to a storm. However, this is also perceived as the most controlled event. Of the least controlled events we have cyber-attack on electronic communication infrastructure, along with an invasion of northern Norway. International and national crop failure is perceived as more controllable and less of a risk than the former scenarios.

In a publication from NIBIO, Bardalen, et al. (2022) noted that the most critical functions in the Norwegian agri-food system can be characterized as those which deal with transportation and consumer-end aspects of the agri-food system. The middle area of their ranking concerns state, business, and technology aspects. The low end of the ranking contains production, communication between state and businesses, and market aspects (Bardalen, et al., 2022:173). It seems that the areas which are the most exposed to complexity and tight coupling are the logistics and supply chain functions as the findings from Yang (2010) also reflects. These also seem to be the most critical functions of the Norwegian agri-food system. However, Bardalen et al (2022) also underline that climate risk knows no boundaries in geography, and therefore climate change increases the risk of composite events where more than one critical region for agricultural production in the global-agri food system could be affected at the same time.

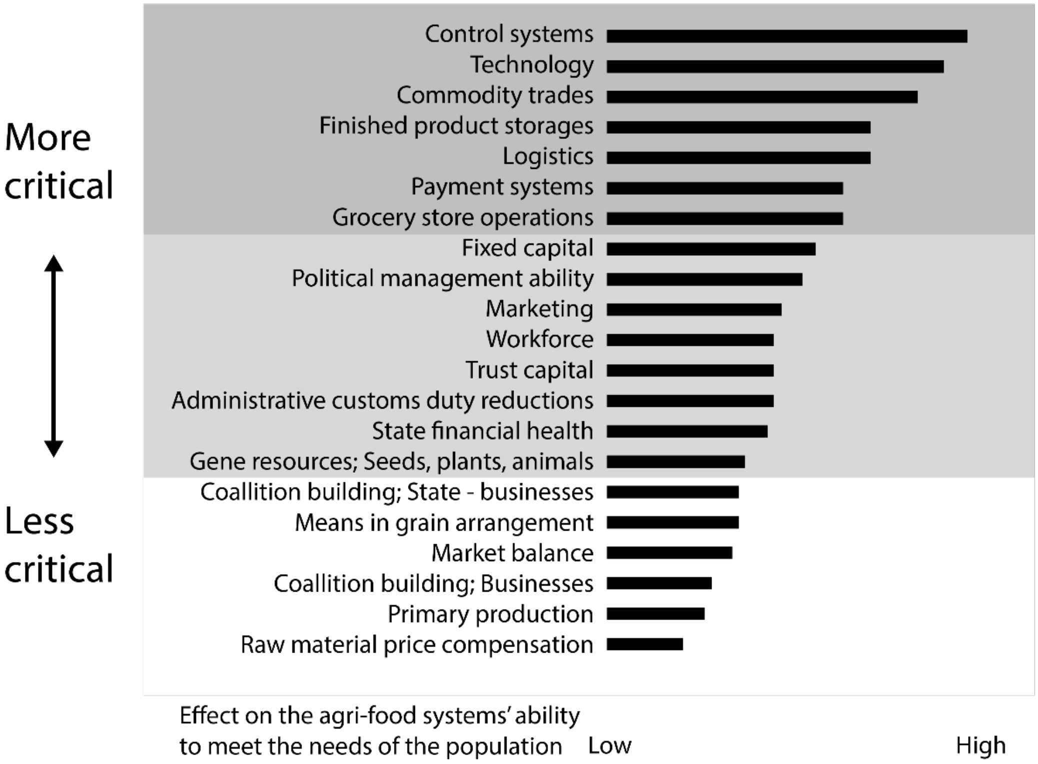


Figure 12 The most critical functions of the Norwegian agri-food system. Adapted from Bardalen, et al. (2022:173).

The goals set for the Norwegian agricultural system by the Norwegian government are: "Food security and emergency preparedness, agriculture across the entire country, increased value creation, sustainable agriculture with reduction in climate emissions" (Bye, et al.,2020:8). The ministries, municipalities and counties collect data and accommodate inter-governmental deliberations between themselves which informs decisions on which measures should be prioritized (Landbruksdirektoratet, n.d.). In addition, there is a yearly agricultural settlement between agricultural unions such as The Norwegian Farmers' Association and the Norwegian Farmers' and Small Farmers' Association (Norges bondelag; Norsk bonde- og småbrukarlag. (2022:10). There are import protections established for various agricultural products. Meat, dairy and eggs have a high custom duty when imported. Vegetables and fruits are also import protected by a moderate custom duty, but only during the Norwegian season. During the off-season vegetables and fruits are not subject to any import protection (Regjeringen, 2021) Most subsidies or 5,3 billion NOK are granted to farms by the Norwegian government towards maintenance of production area in the form of area and cultural landscape grants. Since geographic conditions are limiting on the size of farms in several areas of the country support based on acreage may be necessary based on the previously mentioned goal to maintain “agriculture across the entire country” in order to conserve established farms (Mittenzwei; Britz, 2018:779). These subsidies equate to 22% of the total funding for Norwegian agriculture (Regjeringen, 2023:22). However, to receive these subsidies, the farm area must exceed 1000 m² (Landbruksdirektoratet, 2020a). There are also subsidies which are granted based on the number of produce an agricultural organization has sold. For vegetables and fruits these were decided to be 288,4 million NOK, or 1,2% of total agricultural subsidies in 2023 (Regjeringen, 2023:22). The Norwegian government have regional (RMP) and municipal (SMIL) subsidy programs which are created to motivate existing farms to transition toward sustainable agricultural practices established in regional and municipal environmental goals (Landbruksdirektoratet, 2020b) (Landbruksdirektoratet, 2020c). However, there doesn’t seem to be any subsidies directed toward environmental protection measures which are established already at inception of the farm. As both RMP and SMIL are focused on providing existing farms with funding to put in place environmental protection strategies. Funding also goes toward ecological production, but to receive these subsidies one cannot use easily soluble or inorganic fertilizers. Also, production within built structures such as greenhouses must be in soil. Thus, water with nutrients and non-living soil mediums are thus not allowed (Mattilsynet, 2022b:8, 30). However, Innovation Norway is employed to distribute grants and loans based on 1,49 billion NOK, or about 6,2% of total agricultural subsidies in 2023, some of which can be distributed toward vegetables and fruit agriculture among other agricultural sectors (Landbruks- og mat departmentet, 2023:1) (Regjeringen, 2023:22).

The Norwegian food safety authority (matilsynet) is responsible for monitoring and assessing the status of Norwegian food safety in areas of food safety, plant health, aquaculture health and animal health. While the food safety authority follows the legislation of the Norwegian government the EEA agreement is also enforced in all the areas it overlaps with the food authority’s jurisdiction. In addition, the food safety authority participates in the expert groups which inform the regulation put forth by the EU-commission, and other international forums. The food safety authority also publishes reports on the areas under its jurisdiction (Mattilsynet, 2022a). These reports help to inform stakeholders and researchers in related fields. In general, the food safety authority conducts inspections at any establishment and facility which handles food items, aquaculture, and animal husbandry. In terms of the production and sale of produce, any inspections which deviate from established safety standards affords the food safety authority the ability to ban imports and exports, impose withdraws from the market, destruction, cancellation, or isolation. The food authority can involve the police, customs authorities, coastal guard, and municipalities upon request (Matloven, 2018: § 23). Internal revisions are mandatory, and notifying of the food safety authority is mandatory when infractions with safety standards are found (Matloven, 2018: § 5, § 6).

Norway in general uses less pesticides than other EU countries, as increase in pesticide use is usually associated with warmer climates. In measurements conducted by the JOVA-program it was found 13 percent of all measurements for pesticides in water between 1995 and 2017 were above the environmental safety threshold. In 67 percent of water measurements of Norwegian waters, it was found more than one pesticide at the same time. There has been shown to be on average 2,3 different pesticides per analyzed measurement (Bye, et al., 2020:116). The emergent effects of combinations of pesticides on water-borne organisms is uncertain and could be cause for concern in terms of the negative risk posed to water-borne organisms.

4.3 Results from interviews

In this section the interview respondents' motivations, areas of knowledge, and their contributions to the dataset will be laid out in detail. Furthermore, parts of the data will further be contextualized and triangulated utilizing supplemental sources related to CEA production and Norwegian agriculture.

4.3.1 Experience and Motivations:

Interview respondents 1 and 3 got into the field of CEA with relevant previous experience and knowledge of the main systems involved in CEA. Respondent 1 has experience with electrical engineering, while respondent 3 has a traditional farming background. Interview respondent 2 has an economics background and has gained a lot of knowledge of CEA through his position as a project manager in a start-up aquaponics company due to the wide variety of operational tasks they are involved in. Respondent 4 has gained experience of CEA systems mainly through self-driven research motivated by their goal to set-up a vertical farming business focused on creating equipment and components.

Table 1 Background information about the respondents

Interview respondent	Operational phase	Their relationship to CEA	Location
1	Operational, in production.	CEO of a company manufacturing modular hydroponic vertical farming CEA systems.	Norway.
2	Start-up, R&D.	Project manager of a company in the planning process of constructing a circular, closed environment, aquaponic CEA system.	Norway.
3	Operational, in production.	CEO of a company producing vegetables mainly for hotels and restaurants using hydroponic vertical farming systems located in a greenhouse.	Spain.
4	Start-up, R&D.	CEO of a company focused on research and development of vertical farming equipment and components.	USA, California

4.3.2 Geographic relevance

The decisions for utilizing and developing CEA systems of all the interviewed respondents are connected to geographic relevance in two of the interviews. Respondent 1 noted that the decision to produce vertical farming solutions in Norway is largely based on geography. Access to low-carbon energy and the use-case of climate-controlled agriculture during winter months with low production provides geographic relevance to these kinds of food production systems (1). Respondent 4 also noted that their involvement in the field was triggered due to the geographic relevance. Their state, California, has been experiencing droughts and lack of water for a long time. Since it's a big agricultural state, seeking to find solutions which has an impact on the amount of water the agricultural industry uses seemed like a great idea. This, in combination with the decrease in land costs associated with VF-systems provided a great use-case for CEA systems, since real-estate is particularly expensive in California. Furthermore, respondent 4 also noted their first-hand experience with the consequences of supply chain disruption when they lived in Hawaii. Since the Hawaiian climate isn't the best for growing several vegetable varieties, thus depending on imports, supply chain disruption can cause large increases in food prices (4). Respondent 3 had instead of choosing VF methods on the basis of geographic relevance, made the decision to take advantage of the location (Spain) by utilizing a greenhouse structure, so that energy costs would be reduced (3). Respondent 2's system is planned to be set-up in abandoned or unused horticulture facilities where relevant infrastructure is already in place (2).

4.4 Sustainability and resource use in CEA systems

All of the respondents connect the reasons for their actions to sustainability. Respondents 1,2 and 3 mention the importance of reduction in fertilizer use. Runoff is a big problem in the agriculture industry as a result of large-scale fertilizer usage. There is no way for a conventional open-field farm to stop fertilizer from spreading to neighboring areas (3). (CVA) Greenhouses use a 'run to waste' process, so they dump out all the water with excess fertilizer. In closed-loop systems such as hydroponic vertical farms the water is useful up until you are ready to harvest, that's when you 'flush' to get rid of excess nutrients by introducing non-fertilized water (1,3). Respondent 3 utilizes about two-kilogram bags of fertilizer which last for a month of production. Their crops are flushed once every 6 months, while respondent 1 notes that the amount of fertilizer used in their VF system is negligible when compared to OFA and GH vegetable production.

4.4.1 Development of closed-loop systems

Respondents 1 and 3 utilize closed-loop water delivery systems. However, respondent 2's planned system will utilize a closed-loop model which will attempt to create a closed-loop in the areas of input and output as well. The plan is to allow companies to borrow the production output (the vegetables, and or fruit) and then allow them to only pay for what they used or sold, prompting them to return unconsumed products. The unused product in combination with waste-product from the aquaponic process will be used as inputs in a bio-gas generator which converts them to bio-fertilizer and methane gas which is then used to power the system (2). Thus, allowing for more independence in input resources.

4.4.2 Pesticide use

Neither of the respondents that have operational agriculture systems (1,3) utilize pesticides of any kind. In addition, respondent 2 have no plans to use pesticides in their planned system. Since respondent 3 is located in a warm climate and operates VF within a greenhouse the application of pesticides has a stronger use case than in the system of respondent 1, but respondent 3 notes that the balance of the ecosystem is more important to them than to have complete control of the premises.

4.7.5 Water consumption

All respondents note that circular water systems are a lot more water efficient than CVA systems. In respondent 1's system the amount of water utilized in production depends on to which degree one has control over the system. The only way water is lost is when a door is opened, or if they remove a salad. When you harvest a kilo of salad you lose about a liter of water (1) In respondent 3's case which as noted earlier operates a VF within a greenhouse structure, the water system combines a method of mist and drip system and thus has virtually no evaporation. The farm's water usage is about 3000 liters during a "heavy month" (a month where more water than usual is required) and has the capacity to grow 13000 crops on 112 m2, yielding between 232 and 348 kg/m2/year (3). Thus, the system is estimated to use between 0,92 and 1,38L per kg per m2. Compared to data from Barbosa, et al. (2015) where OFA was estimated to be irrigated with about 250L per kg during their growth period (Barbosa, et al. 2015:6881) we find that respondent 3's water use equates to between 0.36%

and 0.55% of the water use estimated in Barbosa, et al. (2015). In comparison to the example of OFA water consumption used in Romeo, et al. (2018:543) which was a lot lower at 23,2 L/kg/m2, we find that respondent 3's system uses between 3,9% and 5.9% of this. In respondent 1's system which produces 125 kg per m2 per year and loses about 1 L per kg removed, we find that in comparison to the OFA example in Barbosa, et al (2015) and Romeo, et al. (2018) it uses 0,4% of Barbosa's and 4,3% of Romeo's. Thus, both respondent 1 and 3's systems provide a reduction in water use between 99,6% to 94,1% in 3, and between 99,6% to 95,7% in 1, when compared to OFA.

4.4.3 Energy consumption

The VF systems respondent 1's company produces, utilizes about 100w of electricity per m^2 of grow area per day, while recent tests have shown to use only 80w per m^2. Respondent 1 states that on a square meter of growth area their system can produce roughly 125 kilos of salad on 5 sets of shelves. If we have a lighting cycle of 18 hours on and 6 hours off for the growth of romaine lettuce, we find that the LED lighting system utilizes 3 285 kWh of energy per m^2 per year with 100w LED's. With an 80w LED system it would be 2 628 kWh per m^2 per year. This equates to 26,28 kWh per kg of lettuce for the 100w system and 21,02 kWh per kg for the 80w system. However, there are more factors which contribute to the power usage of a vertical farm. According to iFarm (2020), a technology company specializing in IT-driven farming in controlled environments, the electricity usage for a farm of a large size (1000 m^2 growing area) when excluding grow lights is about 33,35 kWh per m^2 per month. This power expenditure is attributed to: Air conditioning systems, computer systems, osmotic dehydration system, fertigation system, pumps, dehumidifiers, air humidifiers, controller and automation, workroom lamps, web cameras (ifarm, 2020). This comes out to an added electricity usage of 400,2 kWh per m^2 per year. Thus, the total energy expenditure of a farm with an area of 1000 m^2 which uses 100w per hour per km^2 to grow 125kg of lettuce would roughly use 29,48 kWh per kg per m^2, while an 80w LED system would use about 24,2 kWh per kg per m^2.

The energy use of LEDs in Respondent 1's VF system per m^2:
100w / 1000 = 0,1 kWh * 18h = 1,8 * 365 * 5 shelves= 3285 kWh/year/m^2
80w / 1000 = 0,08 kWh * 18h = 1,44 * 365 * 5 shelves = 2628 kWh/year/m^2

Combined with additional utilities based on the data from ifarm (2020):
100w system: 3285 kWh + 400,2 kWh = 3685,2 kWh per m^2 per year

80w system: 2628 kWh + 400,2 kWh = 3028,2 kWh per m^2 per year

Dividing by the yield will allow us to find the energy efficiency per unit of yield.
100w system: 3685,2 kWh per m^2/year / 125 kg = 29,481 kWh/kg/year
80w system: 3028,2 kWh/m^2/year / 125 kg = 24,225 kWh/kg/year

4.4.4 Comparison between Norwegian GH and VF on energy use and GHG emissions

If we look at the energy use of the grow lights alone, we see that VF uses about 14,5 to 18 times more kWh/year/m^2 than Norwegian GHA production.

The energy use of GHA lighting in Norway per m^2:
309 126 000 kWh/year / 1 709 000 m^2 = 180,8 kWh/year/m^2

The energy use of VF lighting in respondent 1's system per m2:
100w / 1000 = 0,1 kWh * 18h = 1,8 * 365 * 5 shelves= 3285 kWh/year/m^2
80w / 1000 = 0,08 kWh * 18h = 1,44 * 365 * 5 shelves = 2628 kWh/year/m^2

However, by calculating the total energy used by GHA in Norway by all energy sources we find that they use an estimated 731 285 532 kWh of energy on heating, and natural gas equivalents to electricity, in addition to their grow lights.

- Natural gas: 130 626 000 kWh (SSB, 2019)
- Heating oil: 13,12 kWh/l (Vanheusden, 2020:9) * 1 750 000 l (SSB, 2019) = 22960000 kWh
- Propane gas: 13,97 kWh/kg (Vanheusden, 2020:9) * 7 304 000 kg (SSB, 2019) = 102036880 kWh
- Tree chips: 4,4 kWh/kg (Vanheusden, 2020:9), 1m3 = 206 kg assuming loose volume (Kofman, 2010:3). 62 055 m3 (SSB, 2019) * 206 kg = 127 833 30 kg * 4,4 kWh = 56 246 652 kWh.
- Electricity used for electric boiler (81 863 000 kWh), heat pump (4 043 000 kWh), remote heating (24 384 000 kWh) (SSB,2019).

- Total kWh for all heating: 56246652 + 102036880 + 22960000 + 130626000 + 81 863 000 + 4 043 000 + 24 384 000
  <u>= 422 159 532 kWh</u>
- Total kWh per m²: 309 126 000 kWh lighting + 422 159 532 kWh heating
  <u>= 731 285 532 kWh</u>
  731 285 532 kWh / 1 709 000 m²
  <u>= 427.9 kWh/m²</u>

Since total area of greenhouse production in Norway is 1 709 Acres (SSB,2019), we find by these estimations that the total kWh used per m² in Norwegian GHA is equivalent to 427,9 kWh/m². According to Romeo et al. (2018) Heated greenhouses are shown to produce about 20kg of lettuce per m²/year (Romeo et al. 2018:543), while Norwegian GHAs between 2010 and 2021 on average produced 23,87 kg of lettuce per m²/year (SSB,2022). In comparison to the 125 kg/m²/year produced in respondent 1's VF system, the difference is 5,23 times the production in respondent 1's VF in m² as opposed to Norwegian GHA production. This means that the energy use of VF in this case is 21,02 to 29,48 kWh/kg/m² (80w and 100w LED system) as opposed to 17,9 kWh/kg/m² in Norwegian GH production.
This means that the energy inputs of VF production of the assumed system would be between 24,2 to 29,48 kWh/kg/m² as opposed to 17,9 kWh/kg/m² in greenhouse production. Which means that this example of VF production uses about 1,3 to 1,64 times more kWh/kg/m² than GHA in Norway. However, in order to find how their impact compares in terms of GHG output we need to conduct estimations on their energy use to CO2eq.

- Natural gas: 130 626 000 kWh (SSB, 2019) * 0,2 kg CO2/kWh (Vanheusden, 2020:9)
  <u>= 26 125 200 kg CO2</u>
- Heating oil: 22960000 kWh * 0,264 kg CO2/kWh (Vanheusden, 2020:9)
  <u>= 781 440 kg CO2</u>
- Propane gas: 102036880 kWh * 0,22 kg CO2/kWh (Vanheusden, 2020:9)
  <u>= 22448113,6 kg CO2</u>
- Tree chips: 56 246 652 kWh * 0,009 (Torstensen, 2020:2)
  <u>= 6 249 628 kg CO2eq</u>
- Electricity used for electric boiler, heat pump, and grow lights (remote heating is excluded as it's deemed net zero (Torstensen, 2020:2)): 81 863 000 kWh + 4 043 000

kWh + 309 126 000 kWh = 395 032 000 kWh * 0,008 kg CO2/kWh (NVE, 2021)
= 3 160 256 kg CO2

- Total CO2eq output: 3 160 256 + 6 249 628 + 22 448 113,6 + 781 440 + 26 125 200
= 58 764 637.6 kg CO2eq

We find that the GHG emissions from average Norwegian GHA production is estimated to be 1,44 kg CO2eq/kg/m². While our estimations of GHG emissions from a VF system with the characteristics previously described would output between 0,168 to 0,236 kg CO2eq/kg/m². This comparison suggests that this VF system reduces GHG emissions by about 83,14% in the 100w LED system to 88,33% in the 80w LED system.

- GHA kg CO2eq/kg/m²: CO2eq/m² = 58 764 637.6 kg CO2eq / 1 709 000 m²
= 34,38 kg CO2eq/m²
34,38 kg CO2/m² / 23,87 kg yield/m²
= 1,44 kg CO2eq/kg/m²:

- VF 100w system kg CO2eq/kg/m²: 3 685 kWh/m² * 0.008kg CO2/kWh (NVE, 2021)
= 29,48 kg CO2eq/m²
29,48 kg CO2/m² / 125kg yield/m²
= 0,236 kg CO2eq/kg/m²
- VF 80w system kg CO2eq/kg/m²: 2 628 kWh/m² * 0.008kg CO2/kWh (NVE, 2021)
= 21,024 kg CO2eq/m²
21,024 kg CO2/m² / 125kg yield/m²
= 0,168 kg CO2eq/kg/m²

4.5 Niche and regime interaction in Norway

CEA is not mentioned in the Norwegian government's agricultural plans, guides, or budgets. While there is imitative from the Norwegian government to foster urban agriculture, these plans are mostly focused on small-scale gardens which provide increased green areas in cities and provide learning and community building activities. However, Innovation Norway is currently supporting respondent 2 with their plans for circular aquaponic agriculture so there is interest on part of the governmental infrastructure to aid development of CEA initiatives (2). Unfortunately, current zoning laws are opaque when it comes to the declaration of CEA within buildings as agriculture. If the land isn't declared as agricultural property, but rather as for example industry property, the owner will not be able to apply for any agricultural support from the Norwegian ministry of agriculture. Furthermore, production area of any farm is a determining factor for the number of agricultural subsidies. Since CEA systems such as vertical farms are immensely resource efficient, they don't benefit from these kinds of subsidies, which might be counterintuitive since they are in effect being punished for using less resources (1). In addition, the Norwegian customs protections reduce or remove all customs duties on fruits and vegetables during the winter (Regjeringen, 2021). Since a few large wholesale actors have control of agricultural market demand, there are challenges due to competition from imports. There are no laws and regulations demanding them to purchase vegetables locally (1). In order to alleviate these issues there could be established funding schemes for producers which are able to grow vegetables and fruits during the winter (2).

4.6 Reliability of, and reliability within CEA systems

Thus, since CEA generally utilizes less resources, it also means that they are less dependent on external inputs, leading to increased stability in output. CEA systems are also more stable due to their capacity for year-round crop production (1,2,3,4). Respondent 1 states that the biggest difference between high-tech greenhouse production and the typical vertical farm is that the greenhouse has a range of external weather-related factors which can have a large impact on production. Greenhouse producers generally operate with a lot of uncertainty about costs related to the outside temperature and the corresponding internal energy use. Regarding Norwegian greenhouse production they adds that:

> The way I calculated it showed that there are only two agricultural zones […] that are very suitable for greenhouses (in Norway). Vertical farming is as of today more efficient. The big joker card is electricity, which can become very-very cheap (in the future) […] you will be able to produce more rapidly with more control with vertical farming, but this depends on the price of power (1).

Respondent 3 can produce year-round due to their geographic location (3), a greenhouse in Norway generally won't be able due to the high energy costs associated with heating. However, CEA systems that are located in buildings generally won't last as long without energy as one in a greenhouse will. If power goes out the crops would likely perish after 2 to 3 days. Inn regards to physical security OFA and GH production lack passive controls such as barrier for entry onto the production site. This goes for both insects, animals, plant diseases and humans. Due to CEA often being located within buildings they are generally more secured from vandalism and have a higher degree of food safety than in OFA and GH production (1).

4.6.1 CEA areas of influence on reliability and sustainability of agri-food systems:

Respondents 1 and 2 had the ability to provide their assessment on how CEA production systems would compare to OFA and GHA in terms of potential areas of impact on agri-food systems related to reliability and sustainability. In terms of reliability the respondents agree that year-round production could provide a large impact on agri-food systems by reducing reliance on imports when CVA isn't operational during the agricultural off-season in Norway (1).

Table 2 CEA's impact on reliability compared to GHA and OFA (Based on assessments by respondents 1 and 2)

Impact areas on reliability	Negative impact	No impact	Some impact	Large impact
Year-round production				(1) (2)
Control of production process			Compared to GHA (1).	Compared to OFA (1). (2)
Physical security			Considers housing production in greenhouse structures (2).	VF production within built structures from materials such as concrete (1).
Resource efficiency				(1) (2)
Energy dependence 1,2	(2)	(1)		

Pesticide dependence 1,2				(1) (2)
Fertilizer dependence 2				Fertilizer is created from circular supply chain, with little to no need for external inputs (2).

Table 3 CEA's impact on sustainability compared to GHA and OFA (Based on assessments by respondents 1 and 2)

Impact areas on sustainability	Negative impact	No impact	Some impact	Large impact
Land use 1,2				(1) (2)
Transportation, local production 1,2			Depends on location and market/supply chain (2).	(1)
Biological diversity				(1) (2)
Water use				GHA production can be built as resource efficient as VF, but only a small percentage of the world's greenhouses are built this way (1).

				(2)
Energy use	(2)		Dependent on geographic conditions, places with less sun and low temperatures are more reasonable areas for VF production (1).	
NO2 emissions and run-off				CEAs reduce fertilizer use dramatically compared to OFA. While it also eliminates the risk of run-off, which GHA doesn’t do (1). (2).
CO2 emissions			(1)	(1) (2)

4.6.2 The internal reliability of CEA

The interview revealed that in order to maximize the internal reliability in CEA production is achieved by ensuring:

- Sensors are positioned in the right places (1).
- Having redundancy in sensors, pumps and energy (1,2,3).
- Having software which notifies the staff of errors (1,2,3).
- Having an emergency plan (1,3):
  -If a pump can’t be changed the plants have a cold room, they can be moved to in order to ensure survival or use a different operational pump by making a loop (1).
  -If the nutrient balance is wrong flushing the system can be used as a safety measure (3).

- Software is set up in conjunction with the design of the system, software needs to be customized (1,3).
- There always needs to be someone available to arrive on-call if something happens (1,2,3)

The advantage of the internal operations of CEA systems is that they allow service personnel to be closer to the data, and therefore have more insight into how the health of the system and hence the plants. Sensors gather data on Ph values, Nutrient concentration, dissolved oxygen in the water, temperature in water and air, temperature on the plant leaf, relative moisture, air moisture, airflow and light intensity. It is important to have redundancy in pumps, should have a plan B for all pumps. In fully automated farms there are a lot of parts which are exposed to wear and tear. If the harvester breaks you would need additional service personnel to come in, which would be swifter if the farm is closer to a city (1). Additionally, one should have service personnel available on-call or being notified if the system notifies of any issues (1,2,3). There should be backup power supply (1,2,3) and a backup internet server (1). On a weekly/monthly basis one should wash all grow surfaces and trays. Every cycle we dispose of nutrient water and wash away bacteria. Hygiene is important daily; one should not use clothing which has been outside the facility. Hairnets and beard nets should be utilized. CEAs are generally the perfect climate for mushroom growth, and we don't want to bring in any mushroom spores (1). All sensors except temperature and moisture must be calibrated once a year. Ph sensors need to be calibrated weekly. If a Ph sensor breaks, it's not noticeable to service personnel compared to for example a moisture or temperature sensor, and it could have immediate impact on the plants if Ph values are outside livable threshold (1). Backup sensors and pumps are important to ensure redundancy (1,2,3). One can also set up a threshold in the temperature system which shuts off the air conditioner if the difference between temperature values in the grow area diverges too much from the values the AC-system tells us it is (1).

The largest risks to the reliability of CEA were identified as:

Internal risks:

Active control flaws:

- Hygiene failure (1,2)

Lack of redundancy:

- Component failure with no redundant components (1,2,3).
- Resources, in particular those which need to be ordered such as substrate supplies and fertilizers (1,2).

External risks:

- Energy grid failure (1,2). In the case of respondent 3 this would be failure of their solar panels (3).

5 Discussion

The discussion will converge empirical and conceptual insights in order to answer our problem topic and problem questions. Firstly, we will apply theoretical and conceptual insights to our findings to understand the mechanisms behind why agri-food systems produce negative externalities. Second, a comparison between impacts of CVA and CEA are made to establish if or by how large of a factor increase CEA contributes towards sustainability efficiency. Third, the conditions which influence the transition towards the implementation of CEA in Norway will be established. Fourth, we will explore the characteristics of CEA in terms of requisite variety compared to OFA and GHA, and their control structures and safety constraints will be expounded on. Fifth, the novel contributions CEA could afford to the control structure of the Norwegian agri-food system will be discussed.

5.1 Understanding feedback loops in agri-food socio-technical systems

By utilizing the concepts we've now looked at, we can combine them to understand how social systems, or socio-technical systems, often change by adapting and innovating by introducing interventions according to their goals, but that the se interventions may fall short and only address the symptoms of deeper issues. The issues, or latent dysfunctions (Merton, 1968), are allowed to incubate or accumulate (Turner, 1978) since the adaptation process and the subsequent integration and latent pattern maintainance (Parsons, 1951) of the socio-technical system has blinders on due to adherence to a fragmented worldview (Hollnagel, 2020).

As we introduce monocultures of crops, we are solving the problem of producing large amounts of food efficiently, thus providing food security. However, these interventions cause latent dysfunctions such as increased reliance on further interventions to solve problems arising such as increased disease and pest vulnerability and reduced soil fertility (Worster, 1990:1105). The introduction of further interventions such as pesticides and fertilizers then become the dominant practice. The interactions between the use of pesticides and the environment aren't necessarily relevant to the single farmer, but the compounded emergent interactions of the increased use of pesticides, such as the effects observed during the 1970's with the negative externalities caused by DDT (Tauger, 2020:172) certainly is relevant environmental protection agencies tasked with dealing with them. However, in this case the feedback mechanism took decades to arrive the use of DDT as a pesticide began in 1939, and the cancelation of its use was first started in 1967 (EPA, 1975). Here we can see a process where latent dysfunctions due to adaptation and goal attainment result in an incubation phase where the changes are allowed to precipitate by means of latent pattern maintainance and integration. This results in an increased intractability due to the development of social structures which are not noticed due to the fragmentation of time, space and knowledge (Hollnagel, 2020). The main reasons why the hazards of DDT weren't addressed properly could be connected to the separation in language, knowledge and background as well as goal conflicts on behalf of those closest to the issue at hand. Dunlap (1981) seems to facilitate Turner's (1979) view that the normative value prescriptions in the social system are at odds with the reality of the situation (Dunlap, 1981:143, 237) (Turner, 1978:84-87). However, in the case of DDT the issue seems to also lie closely with the concerns put forward by Leveson (2012), as the use of these pesticides provided increased reliability in food production but degraded environmental safety and sustainability in the process. In other words, the goals of one level in the system hierarchy conflicted with safety constraints at another level, leading to emergent properties, or latent dysfunctions.

Since the solutions applied increase the intractability of the system by increasing the number of parts, speed and scope of changes, mutual dependence and tight coupling, there is a compounding effect of difficulty in goal-attainment because socio-technical system isn't equipped to match the complexity of the disruptions caused by the latent dysfunctions. In the case of DDT standards in environmental protection seemed to degrade over time due to external pressure applied by chemical companies, furthermore it seemed that the standards for pesticides at the time were acceptable as long as they didn't have any immediate negative health effects on humans that consumed them (Dunlap, 1981:6). Which could be viewed as inadequate standards and requirements (Leveson, 2012:236) or as fragmentation in time (Hollnagel, 2020) Thus, the control structure, or socio-technical system didn't have the necessary requisite variety or conceptual slack in knowledge, backgrounds or opposing views (Weick, 1999) (Schulman, 1993) to monitor, detect and take necessary action to remove the hazard.

In light of this we can view our global agricultural systems as a social system which has a set of goals. An event occurs which blocks these goals from being accomplished (such as insects destroying the crops). In response the social system adapts by introducing a new way of achieving the goal (pesticides are sprayed on the crops). This provides positive feedback by reducing the intended insects, while increasing production (manifest functions). These practices get disseminated to the rest of the agricultural sector and training and education in the use of the pesticides is established, leading to a proliferation in the use of the innovation (Integration and latent pattern maintenance). After a while latent non-functions to the agricultural sector starts to emerge, as biodiversity is diminished in surrounding areas, and groundwater is found to have pesticides in them. These are not viewed by the agricultural organizations as risk factors for food-production, as they affect systems outside its conceptualized boundary. Latent dysfunctions later show up as the use of pesticides have severely affected the pollination process because the bees in the surrounding area have died-off, thus resulting in significantly diminished food production, causing agri-food system disruption in the region.

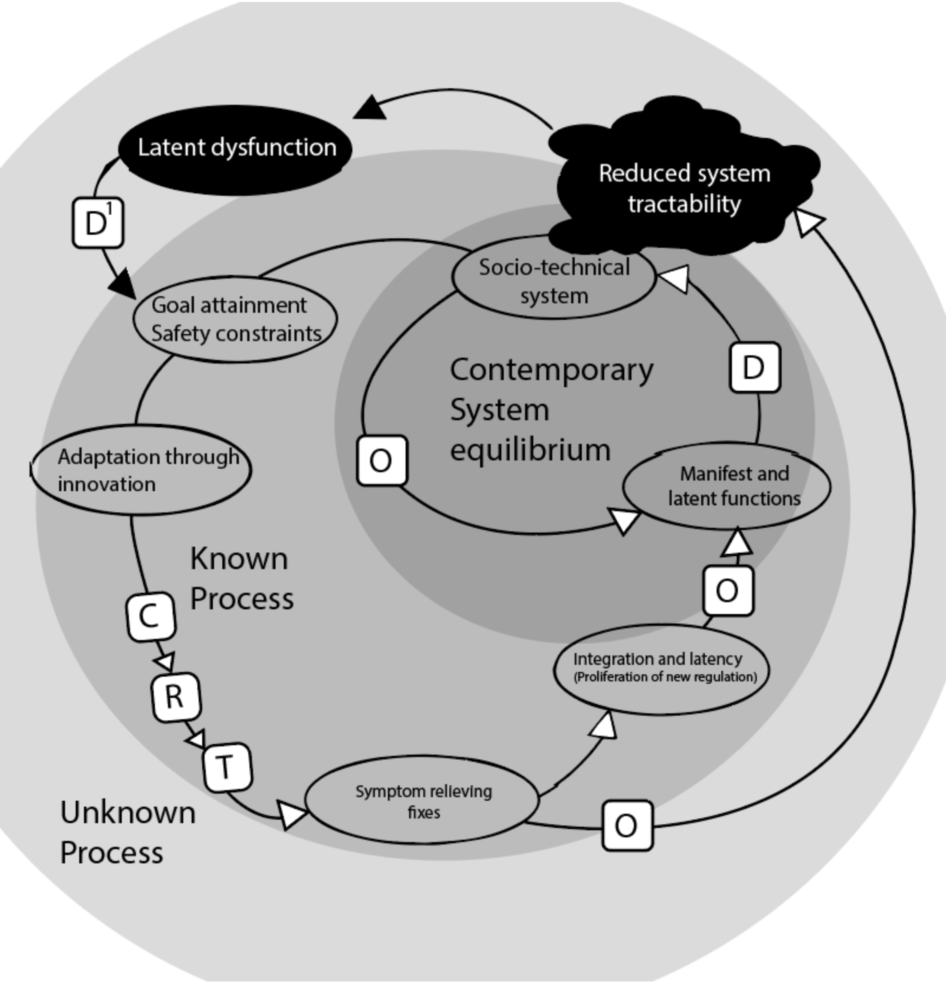


Figure 13 The reasons why latent dysfunctions and reduced system tractability occur.

The feedback loop of agri-food systems can be characterized as a socio-technical system, which adapts through innovation according to its goal to maintain food security, but this adaptation has caused latent dysfunctions to accumulate in the form of farm to biodiversity from pesticides, fertilizers and GHG emissions from the implementation of a globalized food chain. Thus, the integration and latent pattern maintenance has adopted the technical advancements and integrated them into standard practice, which makes up a fragmented worldview, instead of a holistic one. The adaptations applied can increase the intractability of the system by increasing the number of parts, components, subsystems, and external systems involved, the speed and scope of changes, complex interactions and tight coupling from the integration of globalized transportation systems and the dependency on resources from around the globe. There is a compounding effect of difficulty in goal-attainment because the areas of adaptation, integration and latency aren't equipped to match the complexity of the disruptions caused by the latent dysfunctions. In other words, CVA isn't equipped to handle the effects of a warming globe.

> The flow of action continually produces consequences which are unintended by actors, and these unintended consequences also may form unacknowledged conditions of actions in a feedback fashion. Human history is created by intentional activities but is not an intended project; it persistently eludes efforts to bring it under conscious direction. (Giddens 1984:27).

In this way we can see that the process of latent dysfunctions leading to new conditions for actions have roughly transpired in agriculture as such:

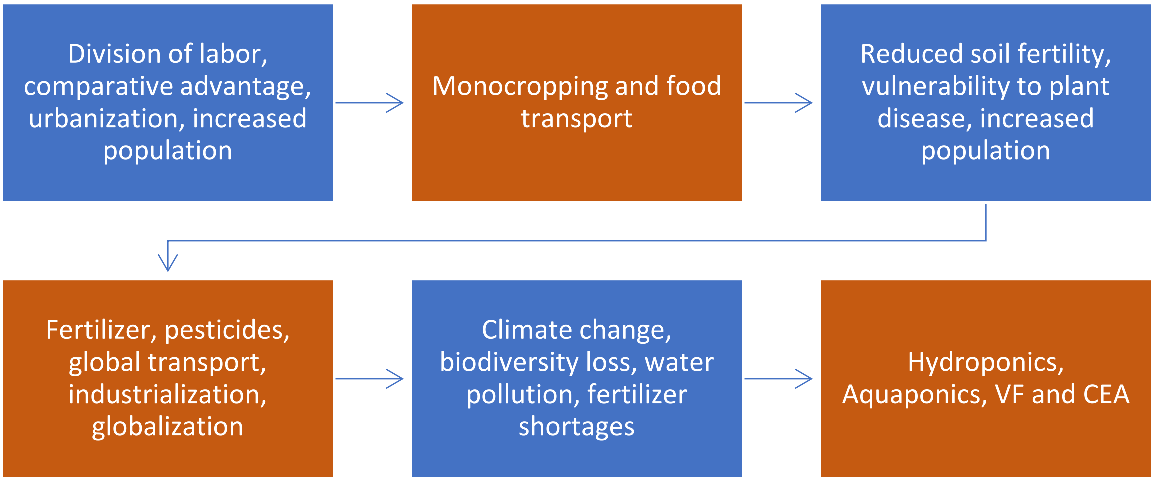


Figure 14 A rough outline of the evolution of adaptation and innovation in response to latent dysfunctions/conditions in food systems

We can show the way in which these technological innovations and adaptations have increased the intractability of the global agri-food system with a simple analogy: The action of breaking a wine glass with one's voice:

> "In essence, the sound passes from molecule to molecule until it hits the glass. As Brunhilde sings louder, she is, in effect, pushing air at the glass harder. The effect is much like pushing a kid on a swing—the harder each shove, the sooner the kid will go over the top. But a strong shove has little effect unless it is timed so it matches the natural oscillation of the swing—just as a hopeful glass breaker must sing a note that matches the glass's resonant frequency." (Schrock, 2007).

Here, some seemingly completely unrelated system interacts with another in an unexpected way, one in which to the sensors available (our eyes in this case), do not detect the events leading up to the destruction of the glass. In the same way, systems we are familiar with may interact in ways which we don't expect. If we wish to solve the problems associated with intractability, we might want to set safety constraints. Using the voice and glass example, we would want to set limits on how high the voice can go, this could be done by using both passive (e.g., insulating the voice from the glass) and active controls (e.g., the source of the voice self-regulating). However, these constraints are not fool proof. Therefore, requisite variety comes into play. One could make the glass in a way which has different levels of thickness, such that no single frequency could cause large damage to it. By this, the increased variety of the glass matches the possible outside variation in frequency of the voice. In a larger system we could have multiple glasses of different dimensions such that very few of them would break due to a specific frequency. This exemplifies the ways in which variety is necessary in order to achieve the kind of redundancy which circumvents common cause and common mode failure (Leveson, 2009:233) or causal independence (Reason, 2016:54). In the case of DDT we see that the dependence on singular inputs can lead to failure not just due to the lack of supply of these inputs, but also the construction of powerful value-structures which lead to ignorance of negative feedback. The glass analogy also serves to outline how a maintained frequency of action may cause feedback loops that are not visible until they cause damage, similar to creeping crises such as climate change (Boin; t'Hart, 2001).

5.2 Landscape and regime push and pull factors on CEA

This section will go over the landscape and regime factors in accordance with Geels (2004) (2006) (2011) multi-Level perspective which provide justification, motivation, and relevance or which may hamper the implementation of CEA within agri-food systems. The regime which we'll refer to is the agri-food regime in Norway.

5.3 Landscape factors

The 2021 State of the World's Land and Water Resources for Food and Agriculture (SOLAW) report provides a comprehensive analysis of the current state of global land and water resources (FAO, 2021). The report highlights several critical issues that need to be addressed for sustainable management and use of these resources. One key issue is soil degradation, which is reducing the productivity and ecosystem services provided by soil (FAO, 2021:10). Human activities contribute to this degradation. Land degradation is affecting one-third of the world's land area, thus impacting the livelihoods of millions of people (FAO, 2021:10). Water scarcity poses challenges to agriculture, food production, and food security, particularly in arid and semi-arid regions (FAO, 2021:xi). Climate change is also a critical issue, affecting the availability and quality of land and water resources, increasing the risks associated with food security (FAO, 2021:xi). Agriculture is responsible for significant environmental impacts. It consumes 38% of the world's land area (FAO, 2021:2), and fertilizer production alone is estimated to generate 1.2% of all anthropic GHG emissions (IPCC, 2019). The transportation of food also contributes to GHG emissions, with vegetables and fruits playing a significant role in global food-miles emissions (Li et al., 2022:446-450). Biodiversity loss affects the provision of ecosystem services and the resilience of food and agriculture systems to climate change (FAO, 2021:56). The COVID-19 pandemic has exposed vulnerabilities in global supply chains, emphasizing the need for investments to mitigate risks of supply chain failure (FAO, 2021:56). Dependence on fossil fuel energy in food production makes food systems vulnerable to supply shocks and increases energy consumption (Heller & Keoleian, 2000:42). The globalization of the food system has led to significant environmental changes and long-distance transportation of food, contributing to GHG emissions (Dicken, 2014:424, 425). Thus, the need for a factor-10 sustainability innovation (Elzen, et al. 2006) within the agricultural system seems apparent, as the access to food is one of the most important critical infrastructures to the human species. These landscape factors function as a push factor to current global agricultural regimes as their practices are put into question.

5.3.1 CEA's emergence in Norway

CEA seems to have emerged in Norway due to the emergence and reconfiguration of technology by social actors scanning the landscape for disturbances to the contemporary agricultural regime. Geographic factors such as a high degree of variation in temperature and ease of access to a low-carbon energy grid makes Norway an attractive location for the development of CEA. However, there are also obstacles to the emergence of CEA presented by the agricultural regime in Norway. These are connected to the removal of value-added taxes on the import of vegetables during conventional agricultural off-seasons e.g., during the winter months (1) (2) (Regjeringen, 2021). In addition, there is variability in the interpretation of Norwegian zoning laws, where meeting the requirements for agricultural subsidies could be hampered by the implication of CEA in industrial rather than agricultural zoning (1). In addition, there doesn't seem to be any benefits awarded to agricultural organizations that have low output of CO2, NO2, run-off and pesticides already designed into the system from inception, as RMP and SMIL funding are awarded to farmers to support the implementation of such measures. Rather, Norwegian agricultural subsidies are currently directed toward incentivizing the reduction of harmful environmental output by subsidizing agricultural organizations in order to allow them to change methods (Landbruksdirektoratet, 2020) (Landbruksdirektoratet, 2020). Thereby, new agricultural organizations that already have environmental safety and sustainability included in the design of their controlled process may be excluded from gaining any benefit of Norway's current environmental subsidies in agriculture.

5.3.2 CEA and its possible impact on Norwegian GHG emissions

Food systems are affected by climate change due to the increased risk of drought, floods and high variability in temperature outside crop-health threshold ranges for extended periods. Climate events seem to be increasing in frequency, and most agricultural systems are particularly vulnerable due to their heavy dependence on the climate being within operational thresholds. Food systems affect climate change through their release of NO2, CH4 and CO2 within operational processes and by their reliance on transport. The vegetable and fruit supply chain emit a much larger amount of CO2 when they rely heavily on imports, due to the large footprint of air travel. The largest contributor to GHG emissions in agriculture is the meat industry through its large-scale output of CH4. In terms of the overall sustainability of CVA we see that it has more notable impacts on factors such as biodiversity and water pollution than it does on GHG emissions. In 2018 in Norway animal agriculture was responsible for 2,29% of annual GHG emissions, while the GHG emissions associated with the fertilization of CVA was about 1,08% of annual emissions (SSB,2022). The literature review conducted found no data on emission from transportation of agricultural products in Norway. However, 2.97% of global GHG emissions can be attributed solely to the transport of vegetables and fruits. The vegetable and fruit supply chains are in total responsible for 4,14% of global GHG emissions. While the meat supply chain is responsible for 7,93% of global GHG emissions. This suggests that there is potential for GHG emission reduction from solutions which enable localization of food production. Thus, the potential for CEA near consumption centers may provide both a reduction in CO2 output when combined with a low-carbon energy grid, and a reduction in CO2 emissions if located near consumptions centers. However, as previously mentioned we won't see a significant reduction in food-mile emissions by supply-end innovation alone. In addition, if CEA is going to be a viable alternative it must be combined with sustainable energy grids and/or receive residual energy from nearby infrastructure, or as in respondent 2's case, generate its own energy, in order to reduce GHG emissions (2).

It seems that CEA does adhere to the signifying characteristics of niche innovations in sustainability transitions. As referred to earlier Geels notes that societal challenges related to sustainability requires factor 10 improvements in accomplishments of sustainability adaptation measures, such as structural changes in transport and agricultural systems (Geels, 2011:471). Considering the findings in our literature review and interviews conducted I contend that CEA-systems have a strong likelihood of providing significant reductions in multiple nodes of emission and resource use in agri-food systems. We have observed factor 10 reductions in the areas of:

Water use: From the literature review we saw that several authors showed that closed-loop water delivery systems could reduce water use by 70 to 90% (Al-Kodmany, 2018:15, Stein, 2021:4) (Shamshiri, et al., 2018:16) (Despommier, 2011:162). From the findings and analysis, we see that the respondents and literature show a strong pattern of at least 90% less water use. As both respondent 1 and 3's systems provide a reduction in water use between 99,6% to 94,1% in 3, and between 99,6% to 95,7% in 1, when compared to the OFA systems presented in Barbosa, et al (2015) and Romeo, et al. (2015). This contribution could potentially help alleviate water shortages in drought prone countries. However, since CEA currently isn't optimized to produce the crops which are associated with the largest blue water footprints, such as maize, wheat, sugarcane, and rice (Mekonnen; Hoekstra, 2010:24) the effect of CEA on this metric would likely be marginal until production system technologies are developed and scaled to include a larger swath of crops.

Transportation: CEA has the possibility of being located within cities, allowing for a potential to reduce transportation and import of vegetables almost completely (1). However, As Petrovics, et al. (2022) underlines; Implementing CEA systems as a singular supply-side intervention doesn't solve these problems automatically. For CEA to become viable in reducing transportation emissions alternative supply chains are necessary which allow for the linking of local producers with local consumers (Petrovics; Giezen, 2022:786) (2). This resonates with the Norwegian supply chain structure where a few wholesalers control most of the market share on the sale of agricultural commodities (1), while a lot of the fruit and vegetable supply is distributed from centralized national storage nodes (large warehouses) for further distribution to regional and local nodes (Bardalen, et al. 2022:178). Thus, in order to avoid one-directional solutions CEA should be combined with local and green supply chains if the goal is to reduce transport emissions significantly (factor-10).

Energy: Our literature review and analysis showed that CEA requires significant amounts of energy, and thus depends on the right conditions in order to reduce GHG emissions (Burgos; Stapel, 2018:12-13) (Petrovics; Giezen, 2022:800). When CEA is combined with a low-carbon energy grid we have demonstrated that it has the potential to reduce GHG emissions compared to the average Norwegian GHA production in direct comparison of GHG output from their energy sources. The average of Norwegian GH was found to produce 1,44 kg CO2eq/kg/m². While an extrapolated example using data from ifarm (2020) and respondent 1 showed that the GHG emissions from this VF system would output between 0,168 to 0,236 kg CO2eq/kg/m². This comparison suggests that this VF system would reduce GHG emissions by about 83,14% in the 100w LED system to 88,33% in the 80w LED system.

Fertilizer: While we didn't receive any direct quantitative data on the use of fertilizers in respondent 1 and 3's systems they mirror the findings from Liu, et al. (2013) and Kozai, et al. (2015) in the potential for closed-loop water delivery systems to reduce fertilizer use, and it's effect on the external environment (Liu, et al. 2013) (Bar-Yosef, 2008:407) due to CEA's capacity to operate without emitting run-off into the environment. As respondent 2 stated they plan on utilizing a closed loop aquaponic system where the excess waste is utilized to create biogas and biofertilizer (2).

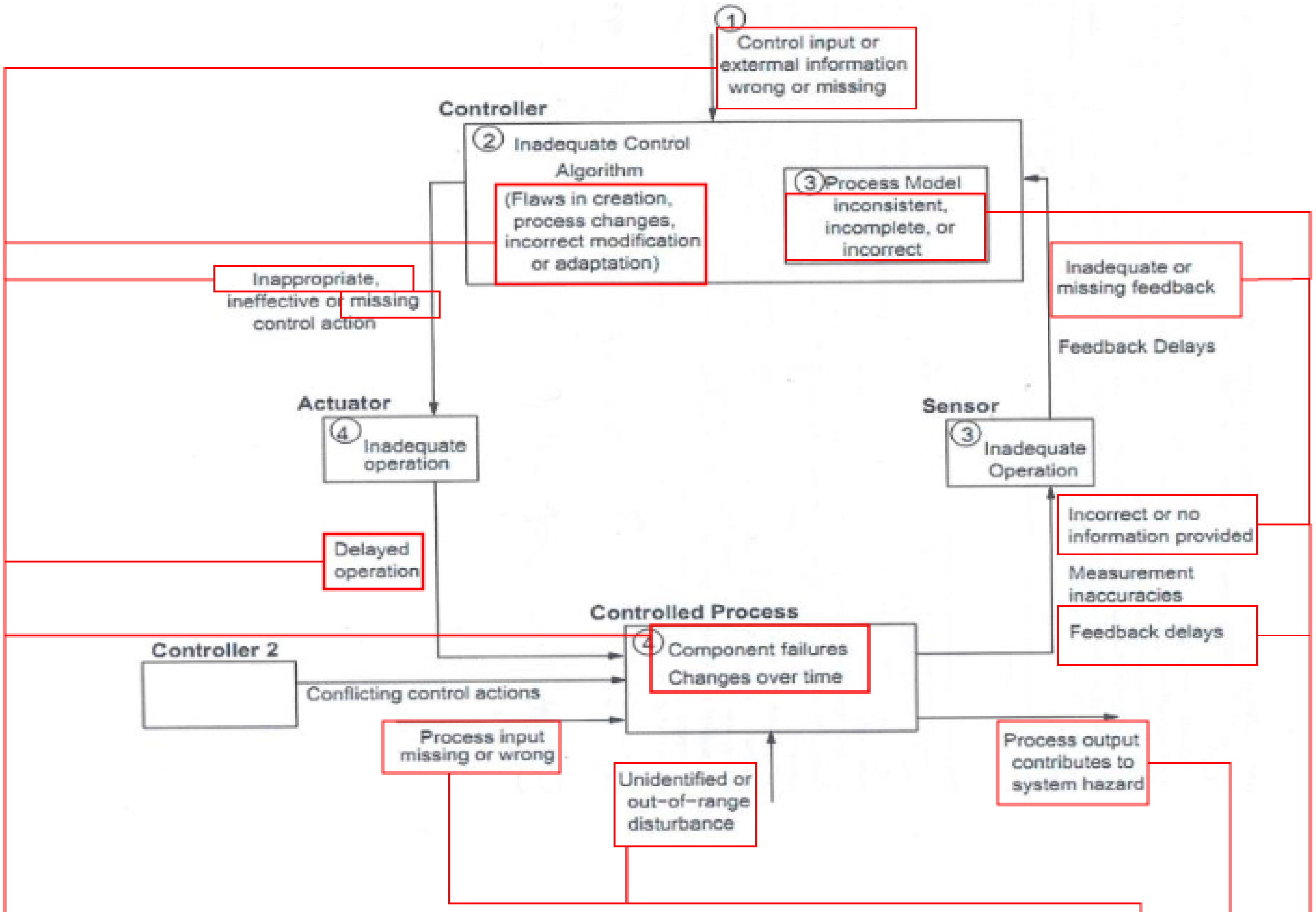
Pesticides: In terms of pesticide use every respondent said they don't use or don't plan on utilizing any pesticides in their CEA systems (1) (2) (3) (4).

As the Brundtland commission states there lies difficulty in establishing a holistic approach to sustainable development this because organizations are generally compartmentalized by narrow tasks, channels of communication and decision making. The problems won't stop spreading beyond their previous borders, so in order to deal with the interconnection our institutions and organizations must change in order to solve them (Brundtland, 1987:256-257). This connects to the views of Turner (1978) and Hollnagel (2020), that latent dysfunction is allowed to accumulate due to "institutional rigidities of beliefs and perceptions" (Turner, 1978:86), silo thinking and interpretation of the world through linear causality. Linear causality promotes the idea that we can find the root-cause after the effects have manifested. The focus should instead be on the conditions that lead to adjustments which in some cases become large enough to be viewed as causes themselves (Hollnagel 2020:107). This view is reflected in the commission through solutions which focus on departing from the 'standard agenda' which deals with problems by concentrating on environmental effects. The ‘standard agenda’ has made important strides, but since the organizations developed around this methodology has a narrow focus on effects, or symptoms. The sources, or root causes aren’t dealt with. Central agencies and ministries don’t maintain strategies on how they will preserve the resources their operations are based on Furthermore, the commission states that mis-aligned focus by solving symptoms which are perceived as pressing through the use of technological development will provide immediate relief but could establish conditions and factors which manifest larger issues (Brundtland, 1987:42). As shown earlier, the Brundtland commission brings forth the agriculture sector as an example of this. In order to mitigate CEA being the next pesticide, GMO or fertilizer, it will be important to not apply the technology from a single supply-end intervention perspective which maintains the one-directional nature of the supply chain (Petrovics; Giezen, 2022:790, 799). Rather, the implementation of CEA in combination with implementations such as low-carbon energy grids and alternative local food supply chains would be needed to make sure that the potential of CEA is utilized fully.

As Petrovics & Giezen (2022) explain, there isn’t a one size fits-all solution when it comes to VF: “ [...] these elements opens up a Pandora box of complexity and unintended consequences, which require careful consideration of contextual conditions for the appropriate applicability for a technology such as VF.” (Petrovics; Giezen, 2022:788). Thus, the implementation of CEA seems to be dependent on multiple processes converging between niche, regime and the landscape level, since system innovations aren’t moved into place by singular entities or developments. (Elzen, et al., 2004:11). As all of the interview respondents have also outlined, all of them have based their decisions on contextual geographic factors. The relevance of implementing year-round agriculture in colder climates, and the access to low-carbon energy (1), the resilience and efficiency in drought-laden areas, the potential to mitigate supply chain failures (4), and the decision to utilize greenhouse structures in areas where it is pertinent in relation to climate conditions and sustainability (3) (2). There seems to be potential within CEA to reduce the one-directional nature of food-chains mentioned by Petrovics & Giezen (2022) to both be exemplifying the linear transactional nature between the social sphere and the supply sphere, while also revealing the diversion of biological and socio-economic systems (Petrovics; Giezen, 2022). As mentioned, respondent 2’s planned system attempts to resolve exactly this issue by introducing a circular supply chain into its business model. This is planned to be achieved by allowing food-distributers to borrow food products, and then return what they didn’t manage to sell to the producer. The producer then uses these products (which normally are wasted) to generate biofuel which creates energy for the CEA food production process (2).

5.4 Classification of control flaws

I have conducted an analysis of the reliability of OFA and CEA utilizing Levenson's (2017) classification of control flaws which can lead to hazard (Leveson 2012:93). In the case of both figure 16 and figure 17, the control flaws are not assumed to just cause hazardous states that can lead to accidents that result in loss of life. Our definition of accident here is expanded to include undesired loss events which could affect agri-food system reliability, such as large-scale crop failure, local crop failure and harm to the surrounding environment. As Leveson (2012) states, the loss incurred by an accident could be focused towards the loss of life, but it can also encompass other losses which are deemed unacceptable in the analysis, these could be financial, information and equipment losses (Leveson 2012:75), the criteria for specifying a certain event as an accident should be grounded in the severity of the loss being of such significance that it should be accounted for in the design and tradeoff process. (Leveson, 2012:266) In terms of food safety and security the controlled processes looked at here may be unsafe if multiple instances of them fail at the same time, or if their process outputs lead to losses.



- Component failure (crop failure) is caused by:
  Incorrect modification/adaptation due to large scale implementation of pesticides, fertilizer, monoculture production leads to inapproprate and missing control actions such as:
- Excessive use of fertilizer -> Reduced organic matter in soil -> decreased soil fertility
- Excessive use of pesticides -> Reduced biodiversity -> Increased risk of unanticipated pests
- No crop rotation due to monoculture production -> Increased risk of ersosion
- Lacking control input through regulatory incentives to guide controller toward hazard minimization.

- Controlled process is not equipped to handle disturbances because of lacking passive controls which can shield against several out-of-range disturbances such as floods, drought. In addition the controlled process is heavily reliant on external inputs such as pesticides, fertilizers, water, fuel which it has no active or passive control over, thus counterparty risk is present. Wrongful application of process inputs can also happen in regards to wrongful application of fertilizer and or pesticides.

- Process output contributes to system hazards in the form of run-off, soil erosion, GHG emission from nitrogen and associated supply chain, biodiversity loss and contaminated vegetables.

- The process model if an individual agricultural company is incomplete because it does not have available data on climate risks in a timely manner on weather events. In addition there is a significant feedback delay in enviornmental data measurement, diagnosis and response due to the elongated system information structure. There is also prevalent cause-effect ambiguity of hazards due to the large amount of agricultural companies involved.

Figure 15 Control flaws in Open Field Agriculture

In OFA the control flaws with associated risk to food system reliability are:

Inadequate control algorithm -> inappropriate control actions -> Process output contributes to system hazard.

- Agricultural organizations' conventional practices involve the application of excessive amounts of fertilizer, herbicides and pesticides that lead to water contamination, reduced biodiversity and reduction in soil fertility. Furthermore, the broader supply chain involved, in combination with nitrogen emissions, has a notable impact on GHG emissions, which in turn increases the frequency of out-of-range climate-related disturbances.

Inadequate control algorithm -> missing control action -> Component failures

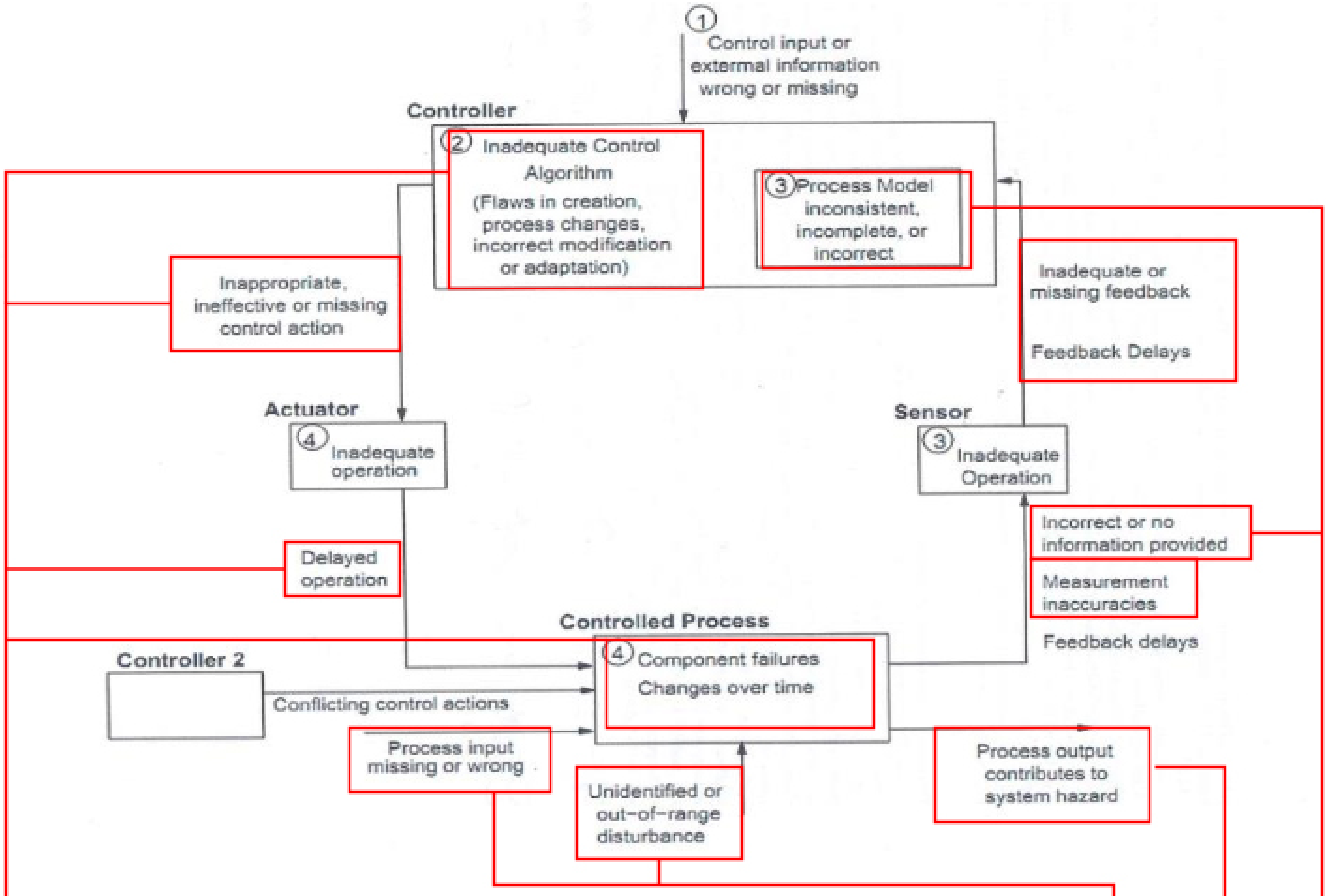
- Agricultural organizations' conventional practices involve monocropping, thus no crop rotation, which increases the risk of erosion, drought and flood vulnerability.

Out-of-range disturbances -> Component failures and changes over time

- There are no active or passive controls present which can effectively mitigate the risks caused by climate disturbances. The only mitigation effort identified which is applied unilaterally in OFA is post-accident funding of agricultural companies affected by crop failure by over 30% of their average yield. If crop failure is prevalent in the food system, it will have a negative effect on food supply.

Process input missing -> Component failure

- Due to reliance on counterparties for most of the inputs in the controlled process out-of-range disturbances to transportation systems could have a severe impact on many agricultural companies by hampering their ability to fertilize and use herbicides/pesticides on their crops.



- Component failure (crop failure) is caused by inappropriate, Ineffective or missing control actions which can stem from both flaws in system design such as software, automated systems or component interaction. They can also stem from control actions which are made by human controllers such as actions made based on misinterpreted data, inadequate resources. Delayed operation could happen as a result of a missing control action such as personell arriving late to an urgency call due to a failed water pump, or a lack of redundant water pumps. The flawed control action with the highest safety risk seems to be missing control action in hygienic routines.

- Process inputs missing can be shorted power fuses and internet outages. Process input wrong can stem from wrongful application of nutrient-to-water ratio and temperature and humidity levels going outside optimal ranges. Out-of-range disturbances can come from energy grid outages, and in situations of disruptions in fertilizer transport.

- Contaminated vegetables seems to be the most likely food system hazard. If the energy the CEA uses isn't renewable it's GHG emissions will be large, and thus will cause externalities outside the system.

- The process model can become incomplete or incrorect due to inaccuracies caused by failure in humidity, Ph, electrical conductivity and temperature sensors, as well as the AC-system. Feedback delays may occurr if sensors fail and human operators aren't able to take measurements in time.

Figure 16. Control flaws in Controlled Enviornment Agriculture

In CEA the control flaws with the highest associated risk factor to food system reliability are identified as:

Missing control action -> Process output contributes to system hazard:

- Hygienic routines are not followed, leading to contamination of vegetables sold.

Missing process input:

- Internal missing process inputs such as shorted power fuses and loss of internet access can have a significant effect on the controlled process. Out-of-range disturbances which result in missing process inputs can also affect CEA's ability to grow vegetables, although likely to a lesser extent than in OFA since CEA utilizes less fertilizer and generally don't use any pesticides or herbicides. However, many CEA's do rely on the delivery of substrate.

Out-of-range disturbances -> Component failures

- Power supply outages are identified as the largest threat to CEA systems reliability since the entire system is dependent on electricity to function. Outages lasting more than approximately 3 days will result in crop failure.

Through the analysis of control flaws I have found that OFA control processes are dependent two systems which are outside the controlled process, namely climate and transport.

5.4.1 CEA control functions

CEA control functions can be characterized as reducing the probability of control flaws in process output contributing to system hazard since the output is mostly contained within its system boundaries by use of safety constraints through passive controls. The investigation conducted only found one potential hazard to output which could occur if hygiene routines are not followed during its active control actions, and it goes unnoticed by personnel. Out-of-range disturbances seem to affect CEA far less than OFA and GH since passive controls are built into the system by shielding it significantly more from the external environment, while reducing its dependence on resources such as fertilizer, water and pesticides. The most important resource to CEA reliability is access to electricity. A central characteristic differentiating CEA from GH and OFA is its need for constant supervision in case of component failure, for example in the case of power-grid failure. However, since OFA is dependent on systems out-of-range of controls implies that they can’t solve problems related most outside-threshold climate events, while GH can’t solve problems related to climate events that involve too high temperatures.

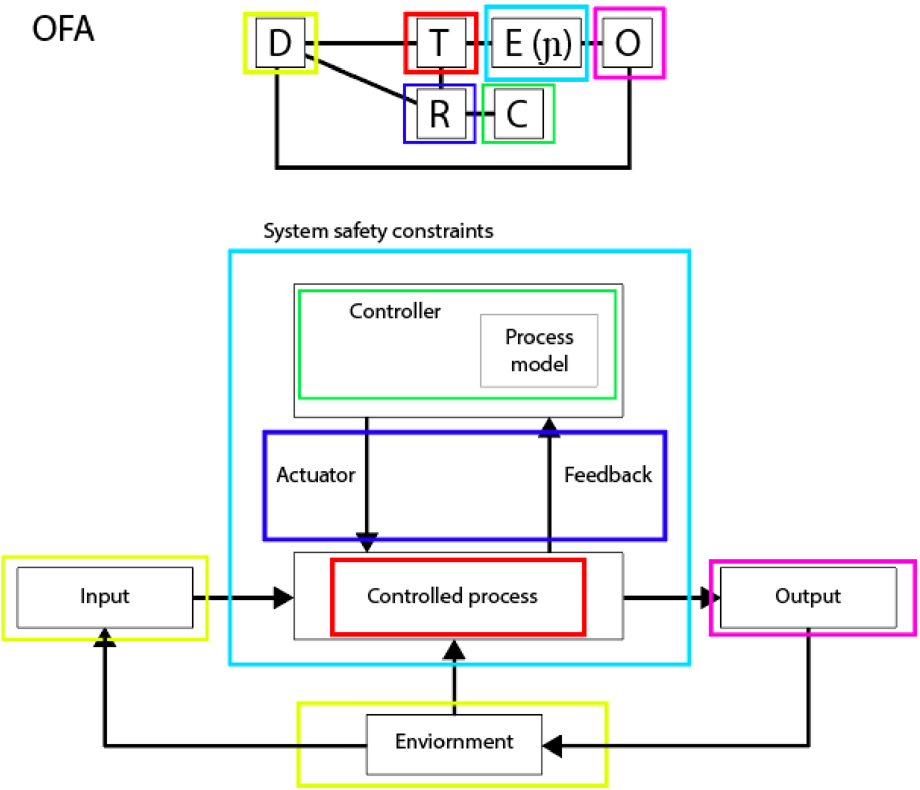


Figure 17. Model of OFA system in relation to requisite variety

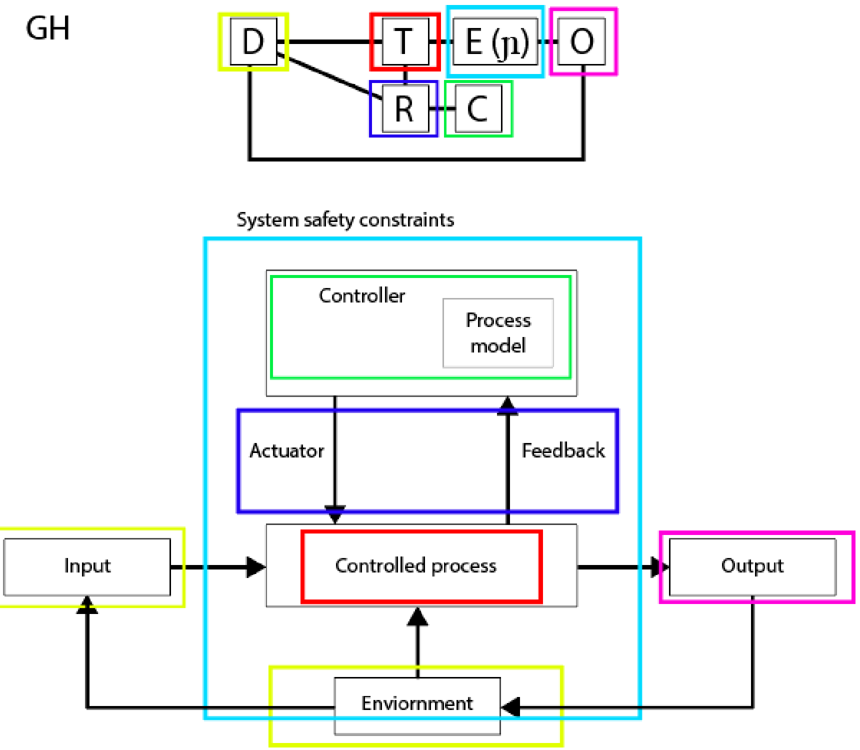


Figure 18. Model of GH system in relation to requisite variety

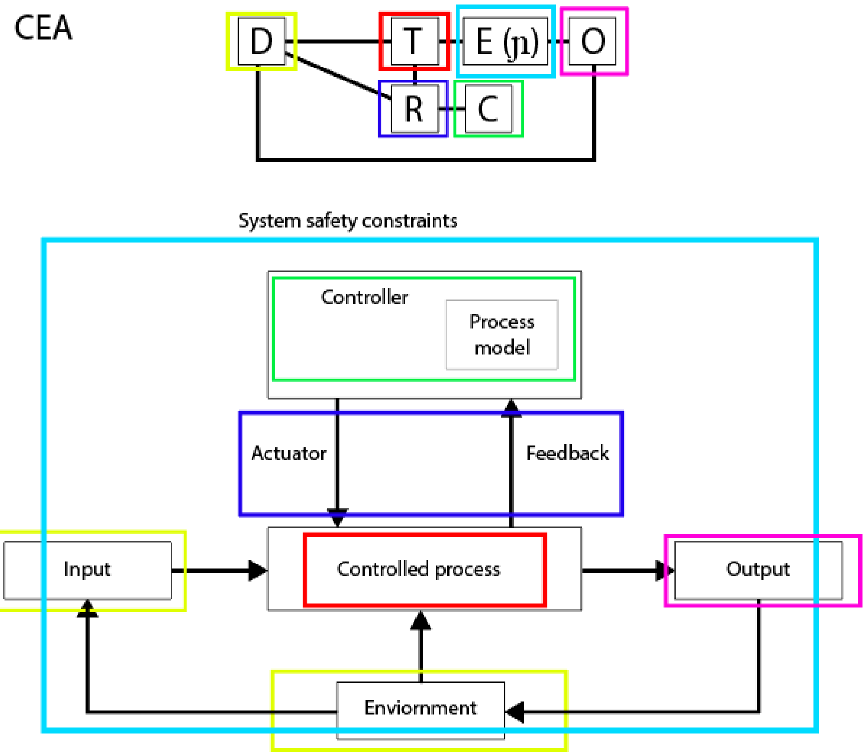


Figure 19. Model of CEA system in relation to requisite variety

We could argue from the functions of CEA presented in the literature review and the findings and analysis, along with the control system characteristics shown in figures (16-20), that CEA systems certainly increase complexity and internal tight coupling by adding several actuators and sensors which the system depends on to function. In view of Perrow (1984) the increased complexity and tight coupling would increase the likelihood of accidents. However, as Leveson (2009) noted, what Perrow doesn't account for is the type of hazard the system is presented with (Leveson, 2009: 229-231). There is more interactive complexity inherent to the internal workings of CEA systems compared to OFA and GHA. However, the complex systems which agricultural organizations are dependent upon to operate are different in character and/or lessened in their ability to cause common cause and common mode failures in CEAs. Agri-food systems reliant on OFA and GHA share the failure modes of:

- Missing process input: Fertilizer
- Missing process input: Pesticides
- Missing process input: Water for irrigation
- Missing process input in logistics (OFA and GHA)/Missing process input (GHA): energy grid
- Missing process input in logistics: e-com
- Missing process input: Payment systems
- Missing process input: Logistics control systems
- Inappropriate (wrong, too early, too late) control action high customs duty during winter (affects short term operation due to seasonal reliance on imports)
- Out-of-range disturbance large scale weather event

While a potential agri-food systems which has implemented large-scale CEA systems connected to alternative local food distribution networks would according to our analysis have the failure modes of:

- Missing process input: Fertilizer (Reliant on less than OFA and GHA)
- Missing process input: Water for closed-loop system (Reliant on less than OFA and GHA)
- Missing process input: Energy grid

- Missing process input: E-com (depending on if the system is capable of operating offline)
- Missing process input: Payment systems (Could be circumvented with direct to customer cash payments)
- Inappropriate control action low customs duty during winter over long periods (affects long-term operation of CEA)
- Inappropriate (wrong, too early, too late) control action high customs duty during winter (affects short term operation due to seasonal reliance on imports)

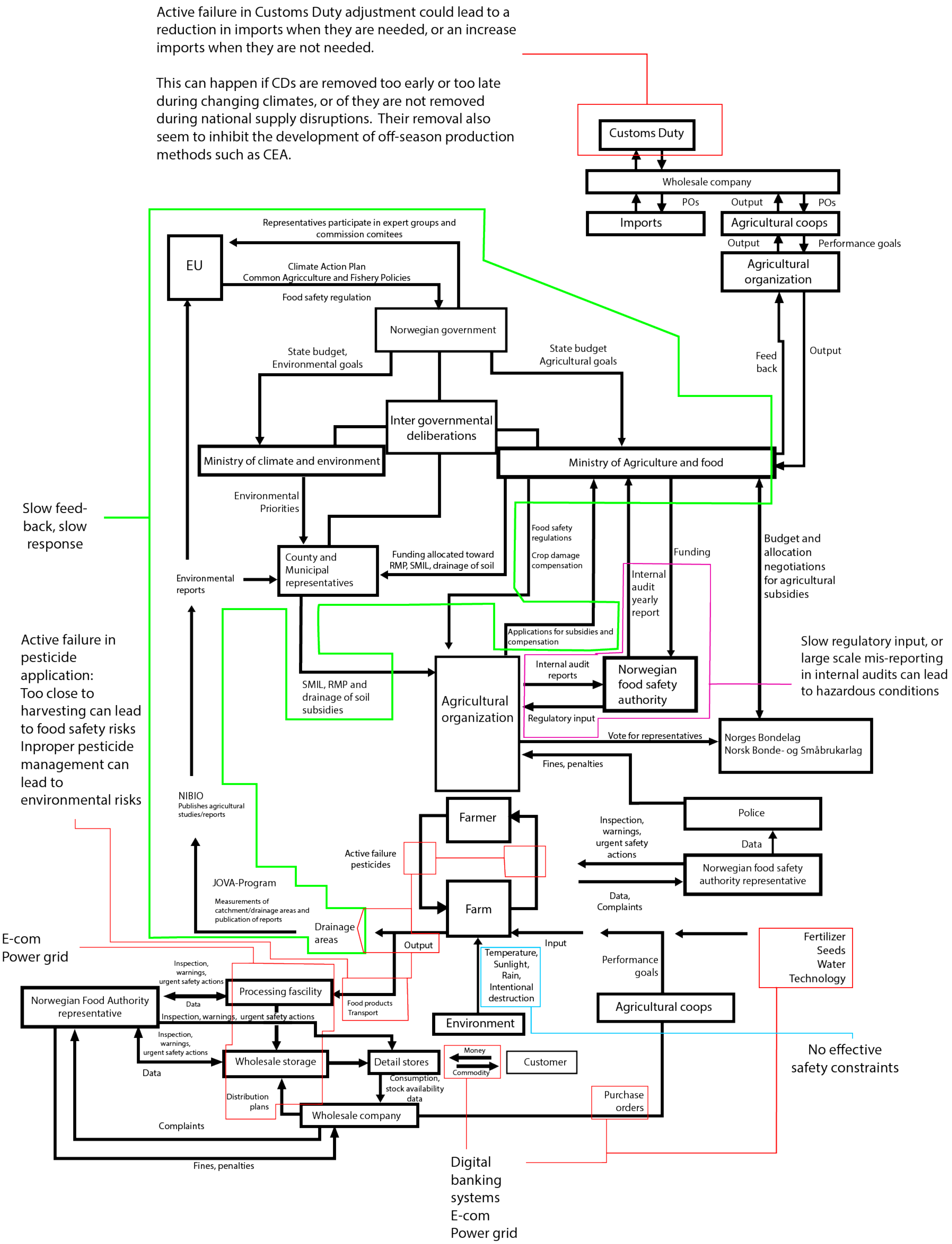
Thus, we see that the common- cause and mode failures between CEA and OFA consist of the missing process inputs: Fertilizer, water, energy grid, e-com, payment systems. However, all of these control flaws except energy grid failure can be different in character in CEAs as they could be designed out of relevance and/or are reliant on a notably lower amount of the same process inputs. Furthermore, in potential agri-food systems which have implemented CEA the customs duty policy contains goal conflicts. As the operations of CEAs enable them to maintain year-round production, but the availability of vegetable and fruit imports to a certain extent relies on a low customs duty during the winter. This goal conflict could potentially be solved by allocating additional agricultural production-based funding towards agricultural organizations which manage to produce fruits and vegetables during the CVA off-season. As such we find that CEAs could provide redundancy by requisite variety to agri-food systems since these production systems are not associated with the same failure modes as OFA and GHA. Adding to this CEA's capacity for resource efficiency, particularly in the areas of water consumption, pesticide use and transport may provide both reliability and sustainability advantages.

5.4.2 The Norwegian agri-food system control structure

Considering the structure of the Norwegian agri-food system which was found through the document review and laid out in the findings and analysis chapter, we will present a model constructed based on this information in accordance with the STAMP framework by Leveson (2012). While this model is quite complex, there are relatively straight-forward interactions inherent in the structure which seem to be the main areas which can result in control-flaws. The green area signifies the control structure in place that are directed towards the feedback process aimed towards measuring and reporting (environmental and agricultural scientific institutions) environmental outputs from agricultural organizations. From there the information is received by several controllers in differing levels in the hierarchy (County, municipal, ministerial, governmental and supernational bodies). The European Union and the Norwegian government both provide goals, policies and funding. The ministries, municipalities and counties collect data and accommodate inter-governmental deliberations between themselves which informs decisions on which environmental measures should be prioritized in funding such as sustainable development, RMP and SMIL funding (Landbruksdirektoratet, n.d.). The funds are then allocated to agricultural organizations which have applied to receive grants, subsidies and/or funding based on environmental measures taken by the individual agricultural organization. One could argue that this control structure has a slow-feedback loop which may have a hard time receiving feedback and converting the feedback into effective control actions and operations in a timely manner. The likelihood that both delays in feedback and in operation seems to be pronounced.

However, the control structure also has lower hierarchical levels which provide restrictive functions based on policies constructed at the higher levels. These include the Norwegian food safety authority, which can deploy the involvement of several law enforcement functions (Matloven, 2018: § 23). Thus, maintaining the ability to serve penalties and swift action at a local level in specific value chain links when their activities move beyond the safety constraints set by the Norwegian government and the EU. However, the Norwegian food safety authority is operating on the basis of control actions provided through established policies by the Norwegian government and the EU such that if feedback delays occur, for example in situations where unnoticed interactions between pesticides cause significant harm to the environment, delays in following operational procedures based on new safety constraints may arrive when significant damage has already taken place. An aspect which contributes to mitigate this is the involvement of the Norwegian food safety authority in expert groups and international forums in combination with their own supervision (Mattilsynet, 2022a) to inform critical food safety action. Furthermore, as mentioned previously control actions made by the Norwegian government could lead to hazardous system states if it adjusts the customs duty at the wrong time. If customs duty is not decreased or removed during the agricultural off-season, or if a combination of a national weather event and the customs duty remains at elevated levels it could result in inadequate amounts of imports to maintain reliable access to food products.

As previously mentioned in congruence with findings from DSB (2017) and Bardalen, et al. (2022), the failure of E-com, power grid and logistics systems could have major implications on the reliability of the agri-food system since the storage and distribution processes on both a national and international scale is dependent upon these processes (DSB, 2017) (Bardalen, et al., 2022).



Active failure in Customs Duty adjustment could lead to a reduction in imports when they are needed, or an increase imports when they are not needed.

This can happen if CDs are removed too early or too late during changing climates, or of they are not removed during national supply disruptions. Their removal also seem to inhibit the development of off-season production methods such as CEA.

Slow feed-back, slow response

Active failure in pesticide application:
Too close to harvesting can lead to food safety risks
Inproper pesticide management can lead to environmental risks

Slow regulatory input, or large scale mis-reporting in internal audits can lead to hazardous conditions

E-com
Power grid

No effective safety constraints

Digital banking systems
E-com
Power grid

Figure 20 The Norwegian agri-food system's safety control structure

Furthermore, payment systems are essential to maintain the functions of the import and distribution of food products as grocery stores, wholesalers and agricultural producers and cooperatives require economic transactions in order to facilitate the distribution and sale of goods between each other and to the individual consumer. Lastly, process inputs are required to maintain the operations of agricultural organizations, these include technology, genetic resources (seeds), fertilizer, pesticides and water. Failures in logistics systems would also have a direct impact on the individual agricultural organization and could result in common-cause and mode failures.

Thus, CEA could provide redundancy through variety by reducing the need for the slow feedback from the green area outlined in the control structure in figure 21 by circumventing run-off and pesticides entirely (1) (2) (3) (4). The implementation of CEA would also likely contribute to the ability for Norway to maintain stability in self-sufficiency in vegetable production during the winter. Furthermore, CEA will likely have a significant impact on the ability in vegetable production of the Norwegian agri-food system during large scale climate events. Furthermore, the more farmers that have reconfigured their systems to include CEA would likely not be as harshly impacted by these events, while the crop damage repayments would also be less strained. This is due to CEA not being affected by common cause/mode events from climate perturbations. However, CEA should be supplemented by other agricultural production methods as large-scale energy grid failures would have a similar impact on CEAs without energy redundancy such as batteries and aggregators (1) (2) (3). However, events which caused large scale energy grid downtime beyond the 3-day threshold of CEA crop survivability would likely have a far more substantial impact on the supply chains the current Norwegian regime is dependent on. The ability to have vegetables already near consumption centers during such events would likely reduce vulnerability more in an agri-food system with both CVA and CEA production methods adequately established, than one with just CVA. Furthermore, a lack of resource inputs due to prolonged supply chain events such as fertilizer and pesticides would likely have a lower impact on the operations of CEAs due to their conservative resource use, particularly since pesticides aren't needed at all in these systems. In other geographic contexts the conservative use of water afforded by the implementation could provide to significantly reduced strain on nearby water supplies.

5.4.3 Crisis management

Could we see requisite variety take place in agri-food systems? There is discussion and exploration happening among governmental bodies, agricultural researchers and farming companies which opens up for diverging theories in the realm of agricultural production methods and technological capabilities. Weick (1987) notes that decision making in HRO's is a decentralized process, but the premises which guide the actors in the HRO are centralized. In this way we can view the agricultural reconstruction which has taken place in the Miyagi Prefecture in Japan in response to the Fukushima disaster in 2011 as High Reliability Theory utilized in practice by local governmental bodies. As mentioned the he development of farming activities with the goal of maintaining collaboration between the marketplace, agriculture and industry. In order to alleviate food production of the stresses caused by salt water and radiation on crop fields, farmers constituted mutual strategies for the development of hydroponic strawberry farms (Monma, et al. 2015:35, xii). By utilizing requisite variety, decentralization of decision making and centralized decision premises and operational goals the Miyagi prefecture also may have alleviated the ills of the reliance on distant supply chains by aiding in creating agricultural organizations which could aid in post-disaster recovery. Thus, mitigating the complexity and risk posed by distant and outsourced food supply (Yang, et al., 2010) (Diabat, 2012) during disaster recovery. In addition the subsequent development of vertical farms in Japan in response to the event could be viewed as an inherent attribute of smaller organizations to develop niches that are involved in rapid adaptation in response to external feedback from landscape pressures, adaptation that inert organizations that make up a regime may struggle to enact. In addition, the potential for CEAs localized operations could be viewed considering decentralization and control slack. Since CEAs have the potential to provide efficient large-scale food production close to market, they could contribute a buffer-zone for agricultural production during large scale common cause and common mode failures in CVA.

5.5 CEA as a reliability transition

As we have seen CEA doesn't just exemplify characteristics of a sustainability transition, its features can in large part be adopted with the objective of increasing the reliability of agri-food systems. In this paper we are not able to measure its impact in terms of a quantitative measure in reliability. However, in terms of the qualitative analysis CEA's control structure in comparison to OFA and GH control structures, and its characteristics of

Requisite variety, by allowing for a wider range of control actions and sensors to provide feedback, thus complexity through an increase in variety of regulatory states means that requisite variety is increased (Ashby, 1956). CEA is an attempt at controlling a complex system (vegetable and fruit production) by enveloping it within a system which addresses its complexity. Instead of attempting to control the environment, the technology attempts to become the environment. Thus, conceptual slack, is also addressed. By implementing CEA in higher-level decision-making processes conceptual slack can by utilized by addressing problems by use of different perspectives, thus taking advantage of a variety in ways of addressing a problem from different angles (Weick; Sutcliffe, 1999) (Schulman, 1993) and providing solutions to problems which can't be addressed by conventional agricultural methods.

Resource slack (Schulmen 1993) is applied through the resource efficiency of CEA in terms of water use which according to our analysis of the data from Barbosa and Romeo in comparison to respondents 1 and 2 seems to offer a reduction of 99,6% to 94,1% in 3, and between 99,6% to 95,7% in 1, when compared to OFA. While we didn't receive any direct quantitative data on the use of fertilizers in respondent 1 and 3's systems they mirror the findings from Liu, et al. (2013) and Kozai, et al. (2015) in the potential for closed-loop water delivery systems to reduce fertilizer use, and it's affect on the external environment (Liu, et al. 2013) (Bar-Yosef, 2008:407).

Control slack (Schulman, 1993) can be applied with the implementation of CEA by reducing the need for central nodes in decision-making processes when it comes to the dependency of supply chain management. During compounding crises, such as the combination of supply chain risk events (Yang, et al. 2010) (Diabat, 2012), with climate events, such as the events which transpired during the summer of 2018 in Norway (Stolt-Nielsen, 2019), CEA could provide control slack by allowing for local solutions to problems which would previously need to be addressed at higher level instances in government and wholesale suppliers.

By reducing fragmentation, we are increasing our ability to look at problems in a holistic way (Hollnagel, 2020), and it becomes rather evident that the design of technology with a holistic perspective in mind from the beginning reduces shortsighted thinking. One could say that the design of CEA has involved applications of technologies from several different fields with the incremental adjustments of several horticultural experts. Now, it comes down to the regime and landscape level decision makers if they wish to involve CEA in holistic design strategies to address the larger picture, as according to the Brundtland commission, this seems like an important aspect of implementing sustainable development. By addressing sustainability, we are also addressing reliability. Since reliability in essence concerns the failure rate of a component. The agri-food system is one of the most essential components of any human system for our survival.

In terms of likely impact on the reliability of Norwegian agri-food systems I propose that large scale adoption of CEA could reduce the vulnerability of the Norwegian agri-food system if an international climate-event affected food production significantly in many countries in the EU. However, the barriers currently present between the CEA niche and regime needs to come down for this to be a possibility. Regulatory frameworks surrounding agricultural zoning needs clarification. Furthermore, if the Norwegian government wishes to incentivize the reduction of vegetable and fruit imports during the winter current import duty regulations may need to be changed if CEA organizations are going to be viable in competition with international imports. Alternative supply chains with a lower amount of distribution nodes between producer and consumer should be established for CEA to reduce transportation emissions and increase the reliability of distribution during scenarios of agri-food system disruption. It seems that the easiest pathway for CEA adoption will be one through reconfiguration of the already existing agri-food system. Vegetable and fruit producers which are already established seem to have an ease of entry into CEA systems as they already hold key access to wholesalers and zoning requirements.

CEA seems to be a control system which increases sensitivity to information, reduces fragmentation of knowledge, founded on altruistic principles, the altruistic principles come into play specifically due to the compartmentalization, or separation of the controlled process from the environment, leading to a reduction of negative externalities. As such CEA may have an increased capacity to maintain dynamic equilibrium by increasing the variety in actuator and feedback parts. These include an increase in the scope of sensors, and thereby amplifying model- and observability conditions of the controller, while increasing action conditions by means of allowing for the control of temperature, humidity, nutrient and pH content in water. The results indicate that CEA is a more controlled process than OFA and GHA which entails a decrease in negative externalities produced as output by the system, while increasing efficiency in all inputs except for energy consumption. However as we have seen throughout this paper this all depends on the context CEA is implemented in.

6 Concluding remarks

Much like the process of driving a vehicle, our systems are designed to provide many small and large adjustments (e.g., applying directional input to a steering wheel) in order to maintain stable output (e.g., maintaining the straight path of a car on the road). However, the design of the car, its interaction with other vehicles on the road and the infrastructure it uses to do so will also influence the reliability of traffic. In the same way our agricultural systems are attempting to achieve the goal of supplying a reliable output of food, by providing small or large adjustments to the soil in the form of pesticides and fertilizers, seeds and irrigation. The design of this process leads to latent dysfunctions in the form of extensive water use, run-off, pesticides affecting biological systems. The infrastructure, or the supply chain in this case leads to the output of GHG emissions, which we saw in Li , et al. (2022) that when it comes to global food transport, vegetables and fruits contribute a 36% of global food-miles emissions Furthermore, 2.97% of global GHG emissions can be attributed solely to the transport of vegetables and fruits, (Li, et al. 2022:446-450). Thus, the infrastructure the car is driving on is currently forcing it to use a lot of fuel to reach its goal. Over time the excessive use of the vehicle may affect its capacities to remain reliable. In the same way as we have shown through the adaptations applied in agriculture which cause latent dysfunctions and will over time by their unsustainable nature affect agri-food systems reliability.

While we haven't been able to address every aspect of agricultural operation's sustainability. We have seen through this paper that the comparative impacts of agricultural operations on agri-food system's sustainability can be characterized by their different means to achieve their goals. In comparison to CEA, OFA utilizes 99,6% to 94,1% in respondent 3's system, and between 99,6% to 95,7% in respondent 1's system, when compared to the OFA systems presented in Barbosa, et al (2015) and Romeo, et al. (2015). CEA has the capacity to reduce transport significantly since the agricultural system can be placed within a city near consumption areas (1), but this is dependent on the creation and maintenance of alternative food chains (Petrovics; Giezen, 2022:786) (2). In terms of energy use the average of Norwegian GH was found to produce 1,44 kg CO2eq/kg/m². While the example analyzed showed that the GHG emissions from this VF system would output between 0,168 to 0,236 kg CO2eq/kg/m². This comparison suggests that this VF system would reduce GHG emissions by about 83,14% in the 100w LED system to 88,33% in the 80w LED system. The respondents' statements on fertilizer usage seems to mirror the findings in the literature review of use of

Liu, et al. (2013), Kozai, et al. (2015) and Bar-Yosef, 2008, all respondents operate or plan to operate closed-loop water delivery systems and thus minimal or no run-off will occur (1) (2) (3) (4). Also, none of the respondents utilize or plan to utilize fertilizer in their systems (1) (2) (3) (4). CEA thus seems to be congruent with the aspects of a sustainability innovation (Elzen, et al., 2006) since it shows signs of contributing towards factor-10 improvements in sustainability metrics when applied in the right context.

Norway's geographic factors, such as temperature variation and access to a low-carbon energy grid, make it an attractive location for Controlled Environment Agriculture (CEA) development. However, there are obstacles to the emergence of CEA in Norway related to the existing agricultural regime. These obstacles include the removal of value-added taxes on imported vegetables during conventional off-seasons, which creates challenges for CEA (1) (2) (Regjeringen, 2021). Interpretations of Norwegian zoning laws vary, and meeting agricultural subsidy requirements may be hindered if CEA is classified as industrial rather than agricultural zoning (1). Furthermore, current Norwegian agricultural subsidies do not provide benefits to agricultural organizations that already have low carbon emissions, nitrogen dioxide (NO2) emissions, runoff, and pesticide use designed into their systems from the beginning. Subsidies are primarily directed towards supporting organizations in changing their methods to reduce environmental harm (Landbruksdirektoratet, 2020). This means that new agricultural organizations that have built-in environmental safety and sustainability measures may not benefit from Norway's current agricultural environmental subsidies.

Requisite variety, a concept introduced by Ashby in 1956, suggests that increasing the variety of control actions and sensors in a system allows for better regulation and handling of complexity (Ashby, 1956). Controlled Environment Agriculture (CEA) is an approach that aims to control the complex system of vegetable and fruit production by creating an environment that addresses its complexity. Instead of trying to control the environment, CEA technology seeks to mimic and encompass the environment. This approach also addresses the concept of conceptual slack, which involves utilizing different perspectives and approaches to problem-solving (Weick & Sutcliffe, 1999; Schulman, 1993). By incorporating CEA into higher-level decision-making processes, different angles and diverse methods can be used to address problems that conventional agricultural methods may struggle to solve.

Agri-food systems that rely on traditional open-field agriculture (OFA) and greenhouse agriculture (GHA) share common failure modes. These failure modes include missing process inputs such as fertilizer, pesticides, water for irrigation, energy grid access, e-commerce infrastructure, payment systems, and logistics control systems. Additionally, inappropriate control actions, such as high customs duty during winter, which affects short-term operation due to seasonal reliance on imports, and large-scale weather events that cause out-of-range disturbances, contribute to the failure modes.

On the other hand, if an agri-food system adopts large-scale CEA systems connected to alternative local food distribution networks, the failure modes differ. In this scenario, the failure modes include missing process inputs such as fertilizer (to a lesser extent than OFA and GHA), water for closed-loop systems (to a lesser extent than OFA and GHA), energy grid access, e-commerce infrastructure (depending on the system's offline capability), and payment systems (which could be mitigated with direct cash payments to customers). Furthermore, inappropriate control actions like low customs duty during winter over long periods, affecting the long-term operation of CEA, and high customs duty during winter for short-term operation due to seasonal reliance on imports, contribute to the failure modes.

Thus, the common causes and failure modes between CEA and OFA consist of missing process inputs such as fertilizer, water, energy grid access, e-commerce infrastructure, and payment systems.

CEA implementation in Norway brings benefits like resilience, reduced environmental impact, and resource efficiency. It circumvents the need for the slow feedback of testing for runoff and pesticide use in Norwegian waters since it can eliminate these outputs (1) (2) (3) (4). CEA enhances vegetable self-sufficiency during the winter, mitigates climate event impacts (1) (2) (3)., thus reducing vulnerability in the Norwegian agri-food system. However, it should be supplemented with other methods to address energy grid failures and supply chain disruptions which affects its own resource inputs (1) (2) (3). CEAs conserve resources and water, reducing strain on supplies (1) (2) (3). Overall, CEA could contribute to a strengthening of the Norwegian agri-food system in terms of reliability and sustainability.

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Figure 8. The broad requisite variety structure: Self-produced.

Figure 9. Requisite variety in a hierarchical control structure contextualized by the MLP: Self produced.

Figure 10. Abductive reasoning: Kovács, G. and Spens, K.M. (2005) Abductive Reasoning in Logistics Research. International *Journal of Physical Distribution & Logistics Management*. 35, 132-144. http://dx.doi.org/10.1108/09600030510590318

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Figure 12. The risks of the agri-food systems and their governability: DSB. (2017). Risiko- og sårbarhetsanalyse av norsk matforsyning. Retrieved 20. 04. 2023 from: https://www.dsb.no/globalassets/dokumenter/rapporter/dsb-rapport-matros.pdf

Figure 13. The most critical functions of the Norwegian agri-food system. Adapted from: Bardalen, A., Pettersen, I., Dombu, S. V., Rosnes, O., Mittenzwei, K., Skulstad, A. (2022) Klimaendring utfordrer det norske matsystemet. Kunnskapsgrunnlag for vurdering av klimarisiko i verdikjeder med matsystemet som case. NIBIO. Retrieved 10. 05. 2023 from: https://nibio.brage.unit.no/nibio-xmlui/handle/11250/3013268

Figure 14. The reasons why latent dysfunctions and reduced system tractability occur. Self-produced.

Figure 15. A rough outline of the evolution of adaptation and innovation in response to latent dysfunctions/conditions in food systems. Self-produced.

Figure 16. Control flaws in Open Field Agriculture. Self-produced.

Tables:

8 Appendix

8.1.1 Privacy consent form signed by interview respondents

While this document was created with the intention of allowing for the research to be published with background information about the respondents such as name and place of work, the decision was made to anonymize the interview respondents. The privacy consent form was created during the beginning of the research and therefore contains slightly different research questions than the final paper. As a note to improvements in future research the privacy consent form should have been updated with the most current research questions at that point in time and should also have been formatted in the Norwegian language to the Norwegian respondents. While the Norwegian respondents of course are highly competent adults that are well versed in the English language it would have provided an even better guarantee for the respondents understanding of the contents.

Do you wish to participate in the research project ‘Reliability of vertical farming systems’?

This is a question addressed to you in a research project where the purpose is to research the reliability and risk reduction potential of vertical farming. In this document we give you information about the goals for the project and what participation will entail for you.

Purpose

This project is a master’s thesis conducted by Bendik Sele Gundersen, a student at the University of Stavanger in Norway.

The purpose of the project is to understand the reliability of vertical farming, particularly in regard to the reduction crop failure risk. The project also seeks to understand vertical farming through the multi-level perspective by Frank Geels in order to understand the role of vertical farms in the sociotechnical landscape.

How reliable are vertical farming systems?

-How can the practice of vertical farming reduce the risk of crop failure from internal and external risks?

-Do vertical farms exhibit the identifiers of a societal niche?

-Can vertical farming be categorized as a sustainability transition?

Who is responsible for the research project?

The University of Stavanger is responsible for this project.

The author is Bendik Sele Gundersen, and the guidance counselor is professor Bjørn Ivar Kruke

Why have you been asked to participate?

The reason for selecting you to be interviewed for this project is a result of your background in the field of vertical farming.

What does participation entail?

The method by which information will be gathered is through video interview using the Zoom application. No video or audio recordings will be taken, the interview will be partially transcribed using notetaking only.

The information gathered will consist of:

Your knowledge of the vertical farming practice.

Your name.

The company you work for.

It is voluntary to participate

Your participation is not compulsory. If you choose to participate in the project you can withdraw consent without giving a reason for your choice of doing so. All your personal information will at that time be deleted. There will not be any negative consequences if you choose to not participate, or if you choose to withdraw your consent after the interview is finished.

Your privacy – how we store and use your information

We will only use the information about you for the purposes laid out in this document. We treat your information confidentially and in accordance with the privacy laws of Norway.

The persons who will have access to the information gathered will be Bendik Sele Gundersen and Bjørn Ivar Kruke. The files in which this information is stored will be in a folder on an encrypted hard drive.

As stated previously your name and the company in which you are employed will be mentioned in the project, if you wish to be anonymous other accommodations can be established.

What happens with your information when we finish the research project?

When the project is finished all files relating to your information will be deleted, except for the finished master's thesis document.

Your rights

As long as you can be identified in the data material you have the right to:

-Insight into what personal information is registered about you, and you will receive a copy of this information.

-Change personal information about yourself

-Delete personal information about yourself

-Send a complaint to the data inspectorate (Datatilsynet) about the treatment of your personal information.

What gives us the right to treat personal information about you?

We treat the information about you based on your consent.

On a mission from The University of Stavanger the Norwegian center for research data – Norsk senter for forskningsdata AS (NSD) has considered that the treatment of personal information in this project is in accordance with the privacy policies of Norway.

We treat information about you based on your consent.

Further information

If you have questions about the research, or wish to utilize your rights, contact:

University of Stavanger

post@uis.no
+47 51 83 10 00

Bendik Sele Gundersen

bs.gundersen@stud.uis.no
+47 99 36 64 31

Bjørn Ivar Kruke
bjorn.i.kruke@uis.no
+47 51 83 15 48

Data Protection Official at the University of Stavanger

personvernombud@uis.no

If you have questions associated to NSD's assessment of the project, contact:

- NSD – Norsk senter for forskningsdata AS on email: (personverntjenester@nsd.no) or by calling: +47 55 58 21 17.

Best regards

Bendik Sele Gundersen Bjørn Ivar Kruke

Samtykkeerklæring – Declaration of consent

I have received and understand the information about the project "Reliability of vertical farming systems" and have had the ability to ask questions. I consent to:

- ☐ Participate in an interview
- ☐ The conductor of the project giving the agreed upon information about me for this project.
  - ☐ Information about me being published in a way that they are recognizable to me

I consent to my information being treated until the project is finished

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(Signed by participant, date)