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BECOMING ECO-LOGICAL WITH SECOND-ORDER SYSTEMS THEORY: SUSTAINABILITY IN RE-ORGANIZATION OF ECONOMIES AND FOOD SYSTEMS

A Thesis Presented

by

Skyler Perkins

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ABSTRACT

Ecological Economics has emerged across disciplines, and has begun to disentangle, not only the relationship between biophysical earth systems and economic activity, but also, fundamental relationships between objectivity, power, value, ethics, perspective and purpose.

In part, this thesis represents an effort to illustrate basic transdisciplinary concepts necessary for understanding the project of Ecological Economics. At present, Ecological Economics is challenged by a seemingly infinite number of available considerations, with a relatively narrow repertoire of impactful mechanisms of control. Given this, it is apparent that the application of Cybernetics to Ecological Economics might provide insights. Cybernetics can help to lend concise language to manners for implementing control and also help to navigate the paradoxes which arise for self-regulating systems. While Cybernetics played an early role in the formulation of the relationship between the economy and an environment with available energy, second-order cybernetics can help to formulate the autonomy of Ecological Economics as a self-regulating system and shed light on the epistemology and ethics of circularity. The first article of this thesis identifies occasions when Ecological Economics has confronted circularity, and explores options moving forward. Ultimately, confronting paradox and circularity provide the means for the substantiation of Ecological Economics.

The food system is prominent within Ecological Economics discourse. It serves as a good example of the ‘emergence’ of coordinated activity. In Cybernetics jargon, we can think of the ‘Food System’ as a symbol for the redundancy found in linked characteristics of particular Ecological-Economic inquiry. For instance, when we consider the food system we can be sure that we are dealing with resources that are essential, both rival and non-rival, excludable and non-excludable, and also highly sensitive to boundaries in scope, and scale, and thus highly sensitive to political and social change. In this sense, the food system acts as a symbol for the coordination of activity, and produces an output which is an input to the Ecological Economic ‘boundary’ between the Economy and the Ecosystem.

The second article of this thesis provides an analysis of GHG emissions within the Chittenden County Foodshed. We conclude that urban agriculture, dietary change and agro-ecological production in concert, provide emission reductions which are not achieved when these options are considered separately. Given these conditions, we see mitigation beyond 90% of current emissions.

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CHAPTER 1: INRODUCTION

The evolution leading to modern capitalism has taken place in the context of various social and political structures, technical capabilities, ecological constraints and affordances and also beliefs about reality, knowledge, and experience. Ecological economics has emerged across disciplines, and has begun to disentangle, not only the relationship between biophysical earth systems and economic activity, but also, fundamental relationships between objectivity, power, value, ethics, perspective, and purpose.

We see the footprint of systems theory and cybernetics in the early path of Ecological Economics theory (Ropke, 2004), particularly in the distinction between the economy and its material and energetic environment. However, perhaps scarred from the narrow perspective of neoclassical economics, Ecological Economics has been hesitant to adopt the inverse insights from second-order cybernetics which deal with circularity and informatic closure; the necessary tools which Ecological Economics would use to define itself against its own environment of concepts and methodologies. This thesis explores opportunities for Ecological Economics to close the circles it has created in discourse, and also looks forward to the emergence of novel structures within the Ecological Economic domain.

Formalizing the relationship between Ecological Economics and Food Systems is important for at least two reasons. The first is that a keyword search for food systems in the Ecological Economics journal (through Elsevier) yields more than 1,900 results, almost as much as ‘sustainable scale’. In this sense, formalizing this relationship will help to distinguish what belongs within the journal and what does not.

The second is that the food system is ‘complex’; and complexity seems to push Ecological Economics to the edge of its theoretical stability.

The food system is at the center of a complex set of tensions. One could call it a messy social, political, economic and ecological entanglement. While agriculture has been shaping the biosphere for thousands of years, technology of all kinds has allowed for rapid expansion of the use of inputs. Industrial agriculture is the leading driver of many ecological parameters beyond their previous states, many of which threaten the viability of human civilization in the long run (Millennium Ecosystem Assessment, 2005; Rockstrom, 2009).

This thesis asks what changes would be necessary in order to create a food system that is compatible with a finite planet, with an initial focus on climate stability, and how framing of the food system impacts the ability to achieve this mitigation.

CHAPTER 2: LITERATURE REVIEW

As a researcher, I have been hesitant to use the first person in writing, however, my own experience is an essential component of this thesis and so I will share aspects of my experience in this thesis. My own experience is important because my 'expectations' preface the discoveries I have made and that which I can offer others. After studying social sciences and many critiques of modern society, I began to study Ecological Economics because I sensed that it offered structural prescription for governance in the Anthropocene. Beginning to study Ecological Economics I soon found myself wondering where the boundaries of the discipline lie, what it means to be an Ecological Economist and exactly what is the Ecological Economy. What I discovered is consistent with my expectation that Ecological Economics offers an actionable prescription for broad societal transition toward healthy life within the boundaries of the Anthropocene. In order for this expectation to be fulfilled, Ecological Economics must reorganize the communication channels which link action and perception in society, but must also, by necessity put a limit on the its considerations. In other words the perspective of Ecological Economics cannot be infinitely pluralistic. In order to achieve this Ecological Economics is enhanced by an understanding of Cybernetics and Second order Cybernetics, which analyze 'communication and control' and 'useful paradox' respectively. From the Cybernetic perspective that entities emerge as a result of past coordinated action, we see an opportunity for Ecological Economics to formally respect the Ecological Economic Food System as a bounded system of coordinated activity which is essential for properly representing the relationship between the Economy and

Ecosystem. Therefore, this thesis generally covers the topics of the Anthropocene, Cybernetics, Ecological Economics, Food Systems, and Climate friendly approaches to managing food systems. The challenge that this thesis offers is that each of these domains are presented as potential transformations of each other. As has been pointed out many times in the past, repeatedly by scholars who write on the notion of cybernetics, there is a certain difficulty in presenting circular concepts in a linear fashion. As this thesis deals with the evolution of each of these domains, the literature review aims to paint a broad and general picture, rather than focusing on specifics.

2.1. The Anthropocene

There is consideration within the earth science community about whether to term this epoch the Anthropocene. The concept has been around for a while with an early introduction by a Catholic Priest (Stoppani, 1873), and has been alluded to since, but gained traction with a wider audience with Crutzen and Stoermer (2000) as well as in *Nature* (Crutzen, 2002). This is being considered because humans have become a defining force in Earth's biogeochemical systems, as several ecological parameters are changing very rapidly. From greenhouse gases (GHGs) (Crutzen & Steffen, 2003), to land surface change (Ellis, 2011 and Vitousek, 1997) to impact on oceans, (Jackson et al., 2001; Pauly, 1998) as well as changes in biodiversity, biogeochemical cycling, the ozone, temperature, climate and more.

Considering changes over geological eras begins to indicate the uniqueness of the environmental conditions we currently inhabit, and the fragility, given the shifting foundations which we build upon. Homer-Dixon et al. (2015) points out that systems, such as our economic and political systems, which develop in unique conitions, (spatially or temporally)prove less resilient. Taking this long view of history might open up minds to the possibility of institutional change. As we take a step back, and consider our current environment in a larger space, we are also being forced to take a step back, and reconsider our institutions in a larger space.

The modern dynamic, and potential for substantial systemic shifts, is frequently characterized in triads: the triple threat of environmental, social, economic collapse, (Schneider et al., 2010) energy, food, environmental demands (Tilman et al., 2009). Ecological Economics emphasizes sustainability, just distribution of resources, and efficient allocation.

Humans have a strong interest in steering collective institutions toward stabilization of ecosystem function. It is therefore useful to understand cybernetics, when reflecting on various forms of control. The term ‘Cybernetics’ was originally derived from the Greek word Kybernetes, meaning Steersman, and was initially referred to as the science of communication and control(Heylighen & Joslyn, 2001).

When we consider long term and short term feedbacks, a particular definition of self-organization is presented: Cyberneticist Heinz Von Foerster suggests that unused potential communication bandwidth is a measure of self-organization, serving as a metaphor for other works (Pask, 1996). In other words, if long term Ecological trends and short term Economic trends are mutually informative, this redundancy measures the capacity through which the system has self-organized, since long term Ecological trends and short term Economic trends, had up until this point been considered as independent, not belonging to a single system. Mutual information can be discovered both through gaining knowledge of interdependence and by explicitly linking systems through coordinated signals and responses. Cybernetics is the science of this understanding, lending formalization and language to the process of self-regulation.

2.2. Cybernetics

The cybernetics movement formally began with a series of interdisciplinary meetings held from 1944 to 1953 that brought together intellectuals such as Norbert Wiener, Warren McCulloch, John von Neumann, Claude Shannon, Heinz von Foerster, W. Ross Ashby, Gregory Bateson, Margaret Mead, Lawrence Frank, Heinrich Kluver, and Lawrence Kubie. These meetings were titled “Circular Causal and Feedback Mechanisms in Biological and Social Systems” (Heylighen & Joslyn, 2001).

Concepts such as complexity, self-organization, self-production, autonomy, networks, connectionism, and adaptation, were first explored in cybernetics between the 1940’s and 50’s, and were derived from concepts such as order, recursion, hierarchy, structure, information and control (Heylighen & Joslyn, 2001). Cybernetics theory evolved in parallel and synergistically with General Systems theory. Cybernetics was later applied to many fields from electrical engineering and artificial intelligence, to therapy, social sciences, and epistemology. Von Foerster (1990) suggests that across all applications of cybernetics, what is invariant is the treatment’ of circularity.

Eventually the analysis of observed systems was applied to observing systems and from this emerged the ‘Cybernetics of cybernetics’. After the initial separation between the “soft” camps (social science, epistemology), and the hard sciences (engineering, artificial intelligence), second-order cybernetics moved to bring the two together, focusing on observation itself. Whereas first-order cybernetics treats circularity in control systems emphasizing feedback; second-order cybernetics focuses on the role which circularity plays in the drawing of distinctions, or describing of the world. This circular descriptive process, according to second-order cybernetics, is expressed in logic (Spencer-Brown, 1969; F. Varela, 1975), broadly in the applied sciences (Cowan, Finkelstein, & Kauffman, 1995), as well as in fundamental applications in autopoiesis (Varela, 2009) and enactive cognition (von Foerster, 1972). It makes sense that the most prominent laboratory for this inquiry was in the domain of human cognition and the study of the nervous system of human and non-human organisms.

Cybernetics can also be put toward humanity's most pressing challenges. We cannot discuss governance without discussing economics, and Ecological Economists offer an alternative to the current paradigm. Both first-order cybernetics and second-order cybernetics have the opportunity to yield insights for understanding the approach of Ecological Economics.

2.3. Ecological Economics

Ecological Economics emerges out of traditions in Economics and Ecology, and arguably cybernetics as well. Ropke (2004) cites the importance of the cybernetics Macy Conferences with some of the origins of the early history of ecological economics. Cybernetics and systems theory give a language and formalization to Systems Ecology with emphasis on energy, stability, and the notion of systems embedded in their environments.

From this scholars such as Howard and Eugene Odum began to draw out relationships between stability of ecosystems, entropy, and energy circuits. The Odums studied whole ecosystems and analyzed their ‘metabolism’, or energetic input and output (Ropke, 2004).

Eventually, this understanding would be applied to the economy. The economy was perceived as a system which uses inputs to produce outputs. (Daly, 1968; Kneese, Ayres, & D’Arge, 1970). Then Nicholas Georgescu-Roegen (1971) published *The Entropy Law and the Economic Process* arguing that scarcity is ultimately a physical reality. There is a notable tension in working to bring together notions of matter and information, physics and economics, and even entropy and matter. After all, to some extent notions such as ‘order’, ‘resource’, ‘waste’ and ‘self-organization’ exist relative to the medium in which they are described. Other conceptions treat the ecosystem from an economic perspective, in which the inputs and outputs are measured in monetary terms.

In the field of economics a re-vitalization or emergence of various environment oriented approaches would arise in the form of resource economics, common property problems, amenity economics, externalities, welfare economics, environmental economics. And distinctly, constraints on civilization in general were considered in Limits to growth (Meadows et al., 1972) and The Population Bomb (Ehrlich, 1968) accompanied by an increased public interest in scarce resources and the impact of pollution.

Second-order Cybernetics can help us to explore the relationship between these two frames of reference (Economy within Ecosystem, and Ecosystem within Economy). Of course, it is paradoxical to suggest that there is a linear causal relationship between two entities which exist in distinct frames of reference. In other words, coordination of these perspectives can hardly be considered a simple ‘emergence’, as each frame of reference, is unraveled by the reciprocal deference to the other frame of reference. Successful recursion must then be understood as the evolution of the relationship which drives existence from 2→ 1, and 1→ 2.

This confusion points to an even greater need for transdisciplinary understanding, but ‘encompassing’ frameworks were often challenged. At different points the transdisciplinary and abstract notions within systems theory and cybernetics would come to be associated with the intentions of particular scholars or applications. Often time systems theory was associated with a naive holism, and in parallel, arguably cybernetics was associated with heavy handed government and central planning, due to its theoretical uptake in Russian Governanment (Gerovitch, 2002).

Arguably these mis-representations parallel a more technical misunderstanding of systems theory and cybernetics which could be described by belief that systems contained single attractor basins. ‘Chaos theory’, introduced in the 70’s was perceived as a more exciting alternative. Of course, the notion of ‘order from noise’ out of which chaos theory arose, was established over 15 years prior in 1960 by an enigmatic and prolific cyberneticist named Heinz von Foerster (Clarke, 2009).

In any case, strict formalizations of the relationship between economic and ecological disciplines were difficult to achieve. Debate ensued (and is on going) as to whether ecosystems should be viewed merely as a ‘resource’ toward economic ends, or if there is an alternative approach in which the economy might be considered subservient (Ropke, 2004).

In 1988 the International Society for Ecological Economics was established and in 1989 the first journal was published. In 1993, Herman Daly introduced the notion of scale to economic policy which regulates the size of the economy relative to the ecosystem.

Thus on the one hand, Ecological Economics had some very narrow and seemingly objective positions and on the other the journal invited a range of approaches for crossing ecological and economic boundaries.

This open invitation yielded two types of variety within the field. The first type of variety is active. That is, Ecological Economists are faced with a variety of instruments or actions through which they might change the world. Discussions within the journal include everything from individual agent transcendence of identity (Jenkins, 2002), to knowledge provision (Spash, 2012), to providing standards for deliberation processes (Vargas et al., 2016), to combining policy instruments (Stewen, 1998), to using specific instruments such a defining monetary policy (Dittmer, 2015).

The second type of variety which Ecological Economics faces is seemingly passive. That is, Ecological Economists are faced with attending to a variety of descriptions of the world. These descriptions may be biological, ecological, economic, social, psychological, transdisciplinary or interdisciplinary. These description have implicit boundary conditions, which ultimately channel resources. This variety asks, ‘Which environment does Ecological Economics inhabit?’, or ‘When and where is Ecological Economics?’

In an attempt to synthesize this variety, Spash (2013) characterizes three overlapping windows in Ecological Economics which he characterizes as a big tent. In this article, Spash contrasts groups within Ecological Economics based on the extent to which they integrate disciplines, and challenge the current social structures and institutions. This discourse could be considered an analysis of the ontic, epistemic and methodical forms which inhabit Ecological Economics.

Implicit in this conversation is a tension regarding not only which actions, and descriptions should be included in the domain of Ecological Economics, but also how many should be included. In other words Ecological Economics is concerned with the proper management of diversity and 'complexity'. This concern arises out an ecological and systemic world view, which depends on pluralism. Ecosystems behave in ways that are complex, meaning non-linear, heterogeneous, and often unpredictable. Ecosystems consist of the unobservable, the unmeasureable, and the spatially heterogeneous, and exhibit complex patterns such as scaling laws and fractals. (Loehle, 2011) Further, political economy is explicit in the framing and naming of eco-"systems" as they are multi dimensional, heterarchical, and sensitive to scope and spatial-temporal decisions. (Bascompte and Sole, 1995, Loehle, 2011) However, this complexity is not merely a property of the ecosystem and the economy, but also the 'internal environment', the repertoire, or diversity of approaches which Ecological Economics maintains.

Further, the two types of varieties (descriptions and actions) entail two types of interaction. The means by which descriptions and transformations (actions) interact can be posed as a philosophical question. I find this variety to be represented most closely in Spash's "New Foundations for Ecological Economics" (2011) in which Spash suggests that Ecological Economics would do well to adopt coherent ontological, epistemological and methodological positions in order to define what is Ecological Economics from what is not.

One way for representing interactions, is to hold descriptions as stable, and select actions which maintain these descriptions, (boundaries), etc.. The second is to hold actions as stable, and select descriptions which allow for the continued selection of self-similar actions. While the former might be called realist, the second might be called pragmatic.

Second-order Cybernetics can be of utility toward understanding the paradoxes which arise when considering the dynamics of self-regulating systems, and the layers of controls which are implemented in order to conserve particular states of the system. We find that as systems evolve 'entities' emerge at a moment in time, based on the coordination of entities at the previous moment in time. As Ecological Economics evolves, particular coordinations will emerge which symbolize parallel activities. In order to maintain continuity, emergent entities can be re-embedded within the original pre-analytic vision. This re-embedding process helps a system maintain dynamic stability. It would seem that one entity which is emerging out of this order is 'the food system'. The food system transcends economic and ecological boundaries and can be seen as distinct from its ecological-economic environment. The food system comprises an entity of related components, allow us to simplify our expectations about some variable states when we know the state of other variables.

2.4. The Food System

The food system is at the center of a complex set of tensions. One could call it a messy social, political, economic and ecological entanglement. While agriculture has been shaping the biosphere for thousands of years, technology of all kinds has allowed for rapid expansion of the use of inputs. Industrial agriculture is the leading driver of many ecological parameters beyond states that characterized the Holocene, many of which threaten the viability of human civilization in the long run (Rockström et al., 2009).

Today, concentrations in power over factors of food production,(Middendorf, 2002) declining diversity in institutions, and ignored ecological constraints are resulting in novel intersystemic risks (Homer-Dixon et al. 2015). Failing food systems can both exacerbate and create the conditions for social instability, often harming the most disenfranchised populations. For instance, (Kelley et al. 2015) argue that food and water shortage have contributed to the development of the current Syrian civil war. Further, between 2011 and 2016, in Syria, 70,000 people died of malnutrition, and disease (SCPR, 2016).

For many, the stability of the interacting forces within the food system are of great consequence. Self-organizing networks are generally seen to go through oscillating periods of order, and disorder, or constriction and relaxation. If a system becomes too fixed, it loses resiliency, and if too ‘open’, it loses coherence. Formally, this “self-organized criticality” has been quantified in supply chain networks (Noell, 2007), and economies (Yakovenko, 2012), and we can consider self-organization as intrinsic to life (Thompson, 2009) and ecological viability. ‘Flows’ can be considered dynamically, for examples as nutrient fluxes or virtual water networks (Dermody et al., 2014). The food system could potentially be characterized by many of these interacting forces. For instance, during the 2008 food crisis, political food riots across the Middle

East, and Latin America were the result of a combination of oil prices, climate change induced drought, and various development and trade policies (Homer-Dixon et al. 2015).

Ecological Economics wrestles with the relationship between this complexity, and a definition of sustainability which has emphasized material throughput. There are a couple of interdependent ways to define sustainability at this level including the concept of ‘thresholds’ and buffers (eg. Rockström et al., 2009), based on the maintenance of certain ‘parameters’. In efforts to include fund-services as a definition of scale, Malghan (2006) defines Ecological-Economic fund-service sustainability as the relative ‘magnitude of services’. These approaches make explicit that ‘relationships’ are at the core of this layer of sustainability; whether it is ‘civilization’, the economy, trade, or health.

A cybernetic, or systems approach may consider the maintenance of ‘variety’(Ashby, 1968) as a measure of sustainability in this layer. Variety is not to be confused with diversity. While the latter relates to the number of distinct components in a system, the former deals with the number of ways in which these components can be linked while maintaining their macroscopic identity; or integrity (Heylighen & Joslyn, 2001).

In this dynamic, the cybernetic system tries to maximize the usefulness of the information corresponding to its control, and minimize the information determined to be coming from its environment. In other words; over time a system does not just ignore the environment; it makes the environment ignorable. Here we find the relationship between thermodynamic entropy and Shannon’s information entropy. By maximizing the correlations between observed transformations of the system, a cybernetic system buffers itself from its environment. Consistent with the notion that systems arrive at steady states of maximum entropy production, cybernetic systems maximize the reduction of the variation of their subsystem (Herrmann-Pillath, 2011)(Hyotyniemi, 2011).

It is out of this ‘drive’ for reduced variation that Ecological Economics searches for greater systems of coordination, such as the food system. A keyword search for food systems in the Ecological Economics journal (through Elsevier) yields more than 1,900 results, almost as much as ‘sustainable scale’. In this sense the foodsystem is important to the past and present of Ecological Economics. The food system may also be important for the future of Ecological Economics, as the complexity of the food system seems to push EE to the edge of its theoretical stability (Spash, 2013).

Many of the core themes which presumably distinguish the ecosystem and the economy coalesce in the context of the food system, including a strong moral dimension and alternative definitions of desirable ends, as well as the presence of characteristics which yield “externalities” in market valuation; eg. agro-ecosystems are complex and have dimensions which are non-rival, non-excludable, essential and non-substitutable (H. E. Daly & Farley, 2011). “The food system” has potential to gain status as a system independent from the market; with accompanying movements such as ‘food sovereignty’, ‘Agroecology’, and ‘food democracy’.

In order to bring forth a ‘food system’, which adds value to Ecological Economics, appropriate boundaries must be drawn which facilitate coordinated action. While science is description oriented, it is important that the boundaries which are drawn around entities of analysis facilitate the possibility of coordinated action. On the other hand, coordination needs to evolve in order to become consistent with relevant scientific entities.

This thesis uses climate change and a repertoire of actions coordinated in a foodshed to illustrate this point. In order to mitigate climate change, action needs to be targeted at entities relevant to gas and nutrient cycles at the scale of unique topographies, agro-ecological systems, soil conditions and bio-regions, as well as in supply chains. Out of this coordination emerges a variety of viable social-ecological systems. The challenge for Ecological Economics is to determine what systems and system boundaries allow for the necessary coordination of actions. This variety can be represented as a state space or topography of attractors. Second-order cybernetics points to the concurrent movement through and modification of this landscape. In other words, as action is taken the set of available actions and relevant ecological entities changes, but perhaps very slowly.

2.5. Climate Change and the Foodshed

At its worst, mainstream debate over the direction of the food system is framed in simple dynamics, namely, the splitting of immense varieties of farming methods and products (Vasseur et al., 2012) into categories of organic and conventional, (Chang, 2012) and analysis of the effect on single dimensions such as yield per acre (eg. Seufert et al., 2012) which mirrors a sharing vs. sparing debate focused on land available for forest cover (Balmford et al., 2005) devoid of local political-ecological context, and remaining inconclusive with regard to health impacts (Benbrook, 2012). While this discussion is not entirely without merit, oversimplification does not do justice to the range of production approaches or social, ecological and health concerns, (Benbrook, 2012; Campbell, Thornton, Zougmoré, van Asten, & Lipper, 2014; Fischer et al., 2014; Snedeker & Hay, 2012; Soga, Yamaura, Koike, & Gaston, 2014; Wood et al., 2015) and naturally narrows the solution space.

Further, these passive boundary demarcations or entities of focus, preclude many viable management approaches, and give power to actors which act on these dimensions and scales. The actions considered, which tend to be farm scale and technologically based, preclude descriptions which offer the leverage necessary to bring about a sustainable approach to food systems, according to virtually any definition.

Improving productivity is generally the agri-business response to mitigating greenhouse gases. By improving yield per acre, land can be spared for forest or other purposes. (Davies et al., 2009; Godfray et al., 2010; World Bank, 2009); World Bank, 2009; Godfray et al., 2010).

In addition to supply chain solutions, additional research has looked at consumer choice. For instance, Peters et al. (2016) conducted an analysis of various diets that we might possibly produce within the United States, and the associated carrying capacity. This research tends to emphasize the benefits of reducing meat consumption (Garnett, 2011), but gives little attention to positive feedbacks that occur with constraint, such as increased input demands for crop production on marginal lands.

Researchers who engage with the particularity of such feedbacks and relationships, tend to focus on developing institutions which promote local solutions to what are often global problems. (Reilly & Willenbockel, 2010, Rammel et al., 2007, Provenza, et al., 2015).

The “foodshed” approach tends to emphasize local food production, but also allows citizens to take responsibility for their health and impact on the environment. Benefits of this approach include the possibility of increased coordination among producers, citizens, consumers, financiers, regulators and researchers. Mutual correspondence of such signals and available actions may bring about the possibility of balanced feedbacks and therefore sustainable management. For instance, when consumers have political power over land which their food is grown on, this correspondence will drive the system dynamics. Examples of food shed inquiries include San Francisco, (Edward Thompson, Harper, & Kraus, 2008) which analyzed the possibility for a purely local diet. British Columbia (British Columbia, 2006) analyzed how much production would need to increase to account for growing population. Massachusetts (Holm, 2001), conducted assessments to determine their self-sufficiency. Research in New York (J. B. Jackson et al., 2001) analyzed the smallest spatial foodsheds that could provide food for every population center in the state. Shelburne Falls, Massachusetts (Dunbar, Hoffmeier, & Rhoes, 2009) has analyzed food security with a particular focus on open spaces and backyard gardens. Thus far, ‘foodshed’ analysis has focused predominantly on food security, though foodsheds also represent an entity of focus for assessing climate change mitigation potential as well as enacting GHG emission reductions.

2.6. A Synthesis

This thesis suggests that Cybernetics might be helpful in articulating the options available to Ecological Economics. One option is to differentiate a food system, which formally can be considered a particular ‘coordination’ of actors which exists across Ecological and Economic boundaries. These actors, recursively treat the action of other actors in their environment as signals for their own action; and thus we find a circular network which moves through a variety of states. Actions are ‘selected’ as viable insofar as they maintain the potential of other actions which constitute the organization of the food system. In this way the ‘food system’ as an emergent regulator of ecological-economic complexity generates outputs which serves as an input for dimensions of ‘scale’. In cybernetic fashion, the regulation of scale also serves as an input into the food system.

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CHAPTER 3: FULL CIRCLE: A RETURN TO CYBERNETICS AND FOUNDATIONS IN ECOLOGICAL ECONOMICS

The evolution leading to modern capitalism has taken place in the context of various social and political structures (Boix, 1999; Torcal and Mainwaring, 2003) technical capabilities (Heilbroner, 1997), ecological constraints and affordances (Daly and Farley, 2011), and also beliefs about reality, knowledge, and experience (Bates et al., 1998; Farmer, 1982; McLure, 2002; Shapiro and Wendt, 1992). Ecological economics represents one attempt to disentangle the relationship between biophysical earth systems and economic activity, but also, fundamental relationships between objectivity, power, value, ethics, perspective, and purpose (Moro et al., 2008; Nelson, 2008; O'Donnell and Oswald, 2015; O'Hara, 2009; Tadaki et al., 2015). Amidst a wide variety of perspectives, one theme central to the transdisciplinary approach to economics has been complexity theory.

Complexity theory emerged from a lesser known and more abstract field of cybernetics, out of which concepts such as networks, self-organization, self-reproduction, autonomy, and adaptation arose in the 1940s and 1950s (Heylighen, 2001). Cybernetics puts the notion of 'control' at the core of observation. This leads to the epistemological insight that the observer and the observed give rise to each other. Stepping beyond the footprints of the Western analytical tradition which has oscillated between mechanical and relativist analogies, the epistemological insights generated within cybernetics have the chance to shed light on the relationship between control, knowledge and ethics in a significant way.

I have two intentions with this article. The first is purely practical. As a student learning Ecological Economics I have found it very useful to engage with cybernetics and control theory. I will explore ways in which this pursuit has opened my mind to many possible paths and opportunities regarding the relationship between the economy and the ecosystem. The second intention is to raise a new awareness regarding the relationships between autonomy, value, information, objectivity and control. In short, second-order cybernetics points toward the importance of taking responsibility for our descriptions of the world.

If this is not embraced we deal uncomfortably with various escapisms. For instance, we might live with the illusion that by tipping our hat to ‘complexity’ we can avoid simplifying, mechanizing and linearizing the world. Further, this understanding challenges the notion that our perspective will be pluralistic, and embedded with context while others are devoid of context and monistic. This means that we should not expect to appeal to metaphysics, ultimate ends, or ontology for direction while excluding our role in generating this hierarchy. This challenges the notion that by employing ‘process’ we avoid the relativism embedded in our relationship with ‘structures’, and that mathematical formalism is somehow a different formalism than any other type of language, which separates the world into categories or sets with relations or subsets. At it’s further reaches, this challenges the notion that putting a constraint on the economy, or internalizing an externality, adheres to the logic of the economy as it was before it was constrained or modified or amended. All of this comes with the caution, that in the evolving oscillation between subjectivity and objectivity, we should not build Ecological Economics on a critique of all things monistic, circular, or closed and expect to develop a unique place in the world. If we do, we risk disintegrating the medium through which we express our values and truths, namely the medium comprised of the distinction between the economy and ecosystem.

An exploration of second-order cybernetics helps make sense of and overcome the subject/object dualism that has been subject of debate within ecological economics, for instance, in Spash's (2011) call for discussion on ontology, epistemology and methodology. The early history of Ecological Economics was influenced largely by cybernetics and systems theory. In Cybernetic jargon, here we see descriptions based on interaction and control (Varela, 1979) (e.g. the economy in the ideal as a steady state dissipative structure). The purpose of second-order cybernetics is not to undermine this vision, but to articulate more clearly how it is brought forth. In the early cybernetic bio-energetic formulations, closure and autonomy were given little attention as they were often defined by a distinction in space such as the boundary instantiation of skin on a biological organism. Second-order cybernetics gives closer attention to the manner in which systems construct their own boundaries defining themselves against an environment. In more broad application, these views might guide Ecological Economics toward it's manifestation as a coherent and autonomous system, (paradoxically) distinct from the theoretical environment it draws upon, (e.g. the ecological economy). This paper first discusses the utility, opportunities and pitfalls of circularity, and then identifies cases where ecological economics confronts circularity and is left with a choice about the path forward.

3.1. Cybernetics and Eigenform (Circularity and Existence)

Cybernetics has been defined as a "branch of mathematics dealing with problems of control, recursiveness and information" (Bateson, 1972), "the science of effective organization" (Beer, 1985), and "the science of defensible metaphors" (Pask, 1966). Heinz Von Foerster (1995) points out that "all of these perspectives arise from one central theme, and that is that of circularity." While complexity theory is newer and more widespread, the formalization of the concise nature of Cybernetics was very informative as a student navigating this territory. Circularity is simple, and yet widely applicable concept and creative phenomenon.

In order to understand second-order cybernetics we have to distinguish between three types of circularity: ontological, epistemological and methodological. Within the ecological economics literature there has been significant discussion of ontological and methodological circularity, but less discussion on epistemological circularity. This discussion is the essential contribution that second-order cybernetics can make to ecological economics.

The three types of circularity are summarized in Figure 1. We often consider elements of social systems and ecological systems as 'complex', coevolutionary, and existing in a landscape of various attractors. Circularity appears in these ontological forms as 'feedback'. These feedbacks can be negative or positive leading to various stable states or dissipation. To achieve this type of circularity we turn an output back into an input. Often, in these 'ontological' cases we are aware of the 'thing', such as an ecosystem, but not all of the processes which lead to that thing's existence. This has been referred to as 'complex process circularity' because we are uncertain about the processes which maintain the product (Kauffman, 2016).

Table 1 Three Types of Circularity

Type of Circularity	Conception of circularity	Example of context
Ontological	Feedback, coevolution	Complex system
Epistemological	Reflexive domain	Identity, boundary between self and other
Methodological	Iteration	Adaptive management

Methodological circularities that address agency may take the form of learning and adaptive management, whereby a learning system modifies its actions, instruments of measurement, and even its aims as it adapts with its environment. Some elements of the process are repeating, but the product and context for this process may not. Often times iterating processes don't lead to patterned results which may become more stable over time. These are found widely in science and mathematics.

Epistemological circularity regards the nature of the relationship between the observer and the observed in the development of autonomy. While the tradition of western analytical thought takes the boundary between subject and object as 'objective' and fixed, second-order cybernetics sees a constantly negotiated boundary made stable through recursive or circular definition. As Von Foerster (2003) points out, "The essential contribution of cybernetics to epistemology is the ability to change an open system into a closed system, especially as regards the closing of a linear, open, infinite causal nexus into closed, finite, circular causality." This process of recursion lies at the foundation of all formal systems, with mathematics as perhaps the most precise example (Kauffman, 2012).

We might call the birthplace of these formal systems a ‘reflexive domain’. In a reflexive domain, an ‘entity’ or thing, such as a complex system, is generated as a representation of the relationship between events, or instances, and an event is generated as a representation of the relationship between entities. A reflexive domain closes this circle upon itself.

A reflexive domain is denoted by Kauffman (2010) as “an arena where actions and processes that transform the domain can also be seen as the elements that compose the domain.” Kauffman warns that, “Mutual feedback of a multiplicity of ongoing processes is not easily described in the Platonic terms of pure mathematics.” He suggests that, nevertheless, a reflexive domain can be defined as a transitive set [A,A] which consists of mappings from A to A.

To further illustrate, contemplate the duality: “Big events in our life change us dramatically; they help us become who we are.” In a reflexive domain, ‘who we are’, is defined by the continuity of those events, which change us. The relation A→ A’ is purely dependent on the subjectivity of an observing system. However, once it is formalized it becomes a constraint for itself.

In terms of defining ‘the economy,’ it depends on its dynamic equilibrium in order to justify its own coherence and consistency. However, this ‘equilibrium’ ‘is’ according to itself. Understood alternatively, the economy is exactly it’s not-self. It changes itself in a continuous manner. With this, we find an interesting relationship between observation and reality. In the words of Heinz Von Foerster (1972): “The logical properties of ‘invariance’ and ‘change’ are those of representations. If this is ignored, paradoxes arise.”

This epistemological claim on events and entities however does not preclude the existence of a reality; in fact, the notion of eigenform necessitates it, at least temporarily. An eigenform can be considered the balance against which any distinction is made possible. As George Spencer Brown (1969) explains, “The perennial mistake of western philosophers has been to assume that nothing has no consequences.”

This pristine balance, according to cybernetics, is what makes objectivity possible. In the context of the economy, an eigenform is the imagination of this coherence or equilibrium which allows for a given exchange to ‘make a difference’ and thus be measured and defined. It is the stability which is threatened by something new, or different.

For example, imagine a function which operates on itself, such as $f(x)=f((x+2)/2)$. In this equation, every place there is an x we must again substitute the equation such that $f(x)=f(f(f(f(f\ldots)$. When we plug any number in, what happens? I will let the reader explore aspects of the ontological, epistemological, and methodological metaphors in the determination and interpretation of this endlessly iterative computation. What is ‘it’, how do we find ‘it’, how do we ‘know’ we’ve found ‘it’? What is the significance of the distinction we make between state and function, when both operate on eachother?

So taken as a metaphor, we may begin to have an intuitive sense of the coalescence of “change and invariance,” grasping the sentiment expressed by Kauffman (2009) that “the familiar objects of our experience are the fixed points of operators." In formalization of observation, such as in physics, this process appears as eigen behaviors.

This notion of a reflexive domain might be the basis of developing the ontic structure of ecological economics. This is consistent with many attempts to understand understanding within ecological economics. For example, Baumgartner et al. (2008) call for a stance between radical empiricism and pure rationalism. Norgaard (1989), early in the field's formalization, expressed a hesitancy to believe in an objective reality independent of the observer and culture. Malghan (2006), Daly and Farley (2011) and Spash (2012) all argue for approaches which surface the link between methodology with a pre-analytic vision. Ecological Economics also emphasizes process thought (Gowdy and Erickson, 2005). Cybernetics gives us a language for contemplating the tension between pluralism, variety and cohesion which has surfaced in moments (Costanza, 1989; Spash, 2012). Cybernetics further helps to mediate our understanding of thermodynamics and statistical mechanics (Lievonen & Hyotynemi, 2013; Herrmann-Pillath, 2011; Kauffman, 2011; Kupervasser, 2017).

When confronted with circularity and potential contradiction, Ecological Economics faces a choice between ignoring contradiction, embracing closure and drawing a novel distinction in pursuit of solid foundations outside of the available operations. The choices which are made will define the particular reference point for an observing system, by defining what exists, what is becoming, and what is sought after. We will face this junction in efforts to maintain the distinction between the economy and ecosystem, between agents and their domain of interaction, ends and means, and ultimately in the development of ontology, methodology, and epistemology. In each case these options will be explored.

3.2. The Ecosystem and the Economy

Ecological Economics concerns itself fundamentally with interaction between the ecosystem and the economy. In what we might call an ‘ontogenesis’, we have two parallel originations of the ‘other’. In the ecosystem, we find the introduction of the economy, and in the economy, we find the introduction of the ecosystem. In the primary phase, we can liken the emergence of each to a ‘disturbance’. In other words, both systems, find themselves ‘disturbed’ by the other. This can be likened to saying “I am not myself, because of it (that thing which is independent from me)”. In order to bring forth this ‘other’, we take what was previously conceived as continuous and draw a distinction. For instance, the economy is no longer conceived to be the same at two different points in time. Why is it different than itself? Because of the ecosystem. Or, the ‘economy’ is perceived as causing big changes in the ecosystem. Second-order cybernetics, introduces the concept that information is not a ‘commodity’ to be passed around, but is a ‘difference that makes a difference’ in the words of Gregory Bateson (1972).

This simultaneous transition from one to two, and from two to one, elicits two visions. At the same time that a system perceives its environment, it is discovering internal incoherence. Second-order cybernetics elucidates this relationship between the internal contradiction and the perception of an external world. Viewing information in this way, we come to the conclusion that knowing, is really not knowing! This should elicit a vision of the economic bureacrat, working hard to get the price right.

On the economic side, we find this with the explicit labeling of ‘externality’.

For instance van den Bergh (2010) characterizes an externality as, "the idea that human interactions or interdependencies extend beyond formal markets characterized by prices and exchange". They are thus 'external'.

This point should be made strongly in it's most general form. While Ecological Economists often reject the notion of 'internalizing externalities', second-order cybernetics suggests that this should not be conceived of as fundamentally incompatible with the basic pre-analytic vision of Ecological Economics. When we look more deeply into the matter, we find that the two pre-analytic visions (the economy as subsystem, and ecosystem as subsystem) share a common boundary; that of a single distinction between the economy and the ecosystem. In either case we are left with two steps to take: identifying which presupposed continuities are being severed, and identifying the way in which interaction with the environment recreates continuity. That these two steps are in essence, redundant, illustrates the cybernetic entanglement of the observer and the observed.

In any case, out of this paradoxical reflexive awareness (eg. the economy is not the economy) emerges linear conceptions of the difference which subsystems make (eg. ecosystems make to the economy). For instance, ecosystems are 'worth' a certain amount.

On the ecological side, we find that the economy is perceived as disrupting a particular equilibrium. The economy might then represent a particular change in an available resource such as energy, matter, or variety (in terms of information), or a contribution to an ecological end such as provision of food, shelter or technology. Notice, we start to walk an interesting line, distinguishing ecological end from economic ends. But this stage of wrestling with what is inside and what is outside, occurs before ‘measurement’ can occur.

Formally, we can think of both of these conceptions as black box approaches to the ‘other’. When the ‘other’ (economy or ecosystem) has been labeled in this manner, this elicits the transition to a goal hierarchy. For instance, now we have to manage the ecosystem in order to manage wealth, and we have to manage the economy in order to manage available energy.

This goal hierarchy is the cause of some controversy within Ecological Economics. This controversy can be seen as resulting from the fact that a single boundary demarcates two distinct pre-analytic visions. Is the primary goal Ecological well-being, in which economic activity is seen as a sub-aim, or is the primary goal Economic well-being, in which ecosystem health is seen as a sub-aim. Do we simply achieve sustainable scale in order to ensure everlasting pareto optimality? For instance, Spash (2012) calls Daly and Farley’s (2004) goals of sustainable scale and just distribution “side constraints”. Further, Pirgmaier (2017) compares the vision of Daly’s steady state economy with fitting neoclassical economics “into a biophysical and ethical corset.” This is quite the image. The presumed suggestion of Spash (2012) and Pirgmaier (2017) that there is an alternative to applying constraint represents a deep challenge for the actualization of Ecological Economics. For Ecological Economics to exist, it is essential to recognize that the perception that something is ‘external’ and ‘constraining’ parallels a discontinuity within that which was priorly conceived as ‘internal’, and ‘autonomous’. Paradoxically, any approach to engaging with the economy as a complete and consistent unity, is bringing to bear a perspective that challenges this unity. In other words, putting a constraint on neoclassical economics is no longer putting a constraint on neoclassical economics. On the other hand, any approach which engages the economy as non-continuous, assumes that there is something 'external' with the capacity to recreate continuity. The difference between treating a unity from outside and a discontinuity, or contradiction from inside, is only the starting point.

This is not to say that Spash (2012) and Pirgmaier (2017) do not raise an essential tension. In each domain, Ecological Economists must identify which relationships are maintained, and which are severed, so as to conserve the former.

To continue, when we engage in either manner with a goal hierarchy we consider a signal flow (control system) in which particular signals are linked to particular actions. In other words, the economy (or ecosystem) as a unity is meaningful in a larger domain; it becomes a symbol for some action (other than itself). Perhaps because Ecological Economists rarely inhabit high leverage arenas, emphasis on linking ecological indicators to substantial economic policy instruments is low. There is also a certain distrust of the available repertoire. For instance, Spash (2012) critiques Daly and Farley (2011) for suggesting cap and trade linked to ecological limits. Daly (2014) suggests that Ecological Economics have largely focused on biophysical dimensions to the neglect of linking economic dimensions. However, there are some examples of attempts to explore the linking of ecological signals to economic operators such as the call for 100% reserve banking (Dittmer (2015). While it is well agreed upon that Ecological Economics is prescriptive, it is less frequently described as an enacted system of control feedbacks. Part of this, is the result of building an identity upon critique of current control paradigms with a logic that dissuades operational closure and the encompassing circularity which arises as systems negotiate inside from outside.

For instance, Beckenbach (1994) points out that, “contrary to the analytical promises of neoclassical equilibrium price theory, there is no reference point in relation to which any costs can be regarded as ‘external’.” In fact, if we introduce the price of ecosystems into the economy this will change the price structures against which they were introduced.

Adding to apprehension is what Vatn & Bromley (1997) point out that the “problem of circularity … relates to the fact that standard externality theory draws conclusions about what an efficient rights structure is on the basis of reasoning that actually presupposes this structure as given.”

When we draw a distinction within the economy, we are in the very same stroke attempting to distinguish what is outside of the economy, and measure the value of this ‘outside’ with the instrument that has been built as if it did not yet exist. When we introduce a new element to a system, this element will modify the conditions under which it was introduced, and thus modify assumptions of optimality. This is true, whether we are introducing an economic element to the ecosystem, or an ecological element to the economic system.

Many ecological economists are comfortable with deliberative democracy as a tool for valuation (e.g. Howarth, (2006) but it is still difficult to find an original starting point; particularly because any measurement of ecological change pertains to stakeholders which exist within the current arrangement of society, and yet the solution space and outcome may change the system boundaries and the distribution on which stakeholders were determined. The general sentiment is captured by Young (2000): "Put this way, the connection between democracy and justice appears circular. Ideal processes of deliberative democracy lead to substantively just outcomes because the deliberation begins from a starting point of justice." For instance, Malghan (2010) explores the interdependence of scale, allocation, and distribution, and discovers feedback between distribution and optimal scale. Figge et al. (2014) assess the inter-related questions of 'if, how, and where' in resource use sustainability. In this we find that assumptions about beneficiaries, victims and resource users are interdependent, and can thus change their own starting points.

At this point we reach an intersection in our efforts to manage the boundary between the ecosystem and the economy.

On the first road, in our relativistic approach we assume a linear relationship between the 'other' and the domain, and further pursue optimality on these grounds. In this view divergent aims are independent; neither system embraces the aims of the other. The perceived stability of the domain is independent of the influence of the other system. For instance, paradoxically, the earth's ecosystem is all encompassing and self-regulating but is threatened by human activity. Or, when the ecosystem is valued, or justice is determined, these changes are not absorbed into their own definition. In terms of scale this approach might be characterized by Malghan's (2006, 2010) sentiment that "In general, it is not possible to compare measured values of scale across spatial and temporal dimensions". This article should not in any way be read as a critique of Malghan's (2006, 2010) work which was actually a major inspiration, as one of the first researchers to confront these issues directly. It is also not meant to be an exercise in modelling, particularly given the distance ahead, but rather a reflection on general approaches to navigating systemic boundaries.

An alternative approach, the middle road, or second road in this discourse, is to recognize our own participation in the system. This is to recognize that from the onset, the manner in which we divide the ecosystem and the economy is rooted in paradox. Both systems are ultimately defined by that which transforms them.

Consider the emergence of the Medea hypothesis which seems to synthesize the Gaia hypothesis and its critiques. The Medea hypothesis suggests darkly that the earth (Medea) is purposefully triggering mass extinctions of multicellular life in order to maintain a microbial dominated state (Ward, 2009). Is this the vision of ecological equilibrium we intend to bring forth? Freedom over which 'equilibrium' we assume points to our own participation. One could argue that Malghan, (2010) takes the first steps toward navigating this approach in defining scale as a deviation from optimal scale. This participatory realism suggests that our own action does not follow perception, but works in parallel. In this, reality is seen as providing the potential for form to emerge, not the events and objects themselves. As Varela (1983) says, "[reality or common] ground is a very feminine quality of making something possible, as opposed to a very masculine quality of 'the out there', that you have to fit into."

As Ecological Economics employs a variety of manners for distinguishing the ecosystem from the economy, the achievement of closure depends on the capacity to re-embed every computation within the domain being computed upon. In other words, we not only step-out, and map new relations, generating new hierarchies, new processes for defining new processes from higher and higher vantage points, we also step-in and embody the domains we regulate. For instance, though sustainable scale emerges out of a vision which distinguishes the economy and the ecosystem absolutely, sustainable scale can be remembedded as a function within both Ecology and Economics. Formally, this perspective employs the 'imaginary' in each step: eg. at the interface of efficient allocation and sustainable scale, we seem to find the statement that economic value is equal to the value of economic value; in so far as it is to remain continuous and persist.

By yielding to autonomy, and conceding our participation, we actually relinquish our autonomy, becoming subject to two criteria. The first, "If you want to learn to see, learn how to act" (von Foerster, 1974). That is, the manner in which we draw boundaries, and link signals to operations depend on recursive stability between the operator and the operand. If these states do not reproduce their own conditions then we face relativism. What is optimal at one point, changes the conditions for its own optimality. As Malghan, (2010) formalizes, consider sustainability, allocation and distribution, as vectors in vector space R3. A trajectory charts a particular path through this course. From a view which considers the dynamical system, we see that these fixed values are in a sense "imaginary". A regime is a next order distribution of trajectories, as movement through the space changes the structural parameters which guide the trajectory. Only, some values will yield self-consistent results, or stability between the various perspectives. In this sense, our own participation is a product of the 'allowances' of the environment. Life can be characterized by "drive toward fractal balance of functions in an environment (Hyotyniemi, 2013).

The second criteria given by von Foerster (1974) is to "Act always so as to increase the number of choices." This is our ethical imperative. By acknowledging our own participation, we acknowledge other 'selves'. By actively expanding the number of possible states which the system can fall into, (while maintaining stability), we allow an unknown environment to select from our repertoire. In this process, we find that we can relax many of the controls we have previously implemented to maintain boundaries. In this vision, it is imperative that unnecessary linked operators (or unjustified linear assumptions) are unlinked. For instance, to transition away from the imperative of economic growth drastically frees resources and expands the state space of possibility, while maintaining the capacity to grow the economy maintains operational variety. Currently, economic and ecological control systems depend on a large number of goal hierarchies, which generate noise and friction. Pursuit of redundancy between ecological and economic visions allows for relaxation of these controls. In this vision the 'order' of goals is less important, as it is only when they are coherent that either entity is justifiable.

On our third road, we pursue an independent objectivity, which we do not find within the current system. In the most extreme sense, this road is likened to saying that there is no such thing as the economy or the ecosystem; there is no foundation on which to claim that either of these entities exists. Many critiques from Ecological Economics have revolved around assumptions of analogies to equilibrum within neoclassical economics. For instance, Amir, (1995) among others critique the assumed conservation of utility, Georgescu-Roegen (1971) points out that economics is mechanistic in that there is assumed to be no qualitative change in function or context. Daly (1995) among many others critique the notions of ‘circular flows’. On the one hand, this is perfectly reasonable because after all, self-organizing systems do not exist independent of an observer (von Foerster, 2003). The phenonemon depends on an observer constantly willing to re-draw boundaries; to separate order from noise. On the other hand, this might be likened to shooting oneself in the foot. When there is no equilibrium, there is no stability against which change can be measured, a difference can be made and thus information can be gathered. The fact that a conception of thermodynamics (linearity) is used in service toward a vision for continuity of existence (circularity), comprises the fundamental paradox which Ecological Economics faces in navigating boundaries between system and environment. ‘Order’ is perceived relative to disorder, or, relative to the language in which a description might appear redundant (von Foerster, 2013). Maintaining two distinct and co-operational languages is the challenge.

Often when circularity is critiqued, there is an assumption that we might find foundations outside of the current domain which inform how the distinction between the aims of the ecosystem and the economy should be drawn. A strict intolerance for equilibrium, stability, and circularity are a call for revolution. Not that revolution is necessarily wrong, though its inspiration may be misguided.

As is popularly conceived, Kapp (1970) argues that ecological disruptions are not mere externalities but broad failures of the market system as a whole. This view, while intuitively appealing, has deep connotations. On the ecological side, the perception of continuity in ecosystems exists across many scales and dimensions. For instance, the Gaia hypothesis, has suggested that the earth’s ecosystem as a whole is a complex adaptive and self-regulating system. That there are many elements of the earth's ecosystem (eg. the economy) which actively disrupt the course on which global systems were perceived to be tracking, has resulted in the claim that 'Gaia' doesn't exist.

When we do not find our solid foundations within the operations of the system, we relinquish these boundaries and seek solid foundations outside of this domain. This is to suggest that the boundary of the ecosystem and the economy must be informed by an objective foundation which exists outside of these domains.

"You are a jar; fate is a stone. Kick against it, you'll waste your wine."

-Rumi (Harvey, 1994)

3.3 Ends and Means

One way in which the boundary might be informed by the environment of Ecological Economics is by determining 'ends and means' in a process which is external to the Ecosystem and the Economy. For instance, Daly and Farley (2011) seem to suggest that Ecological Economics occupies a space between ultimate means and ultimate ends. This use of the notion of 'ultimate', seems to be necessary, such as the distinction between classes and sets in the foundations of mathematics. However, we soon find ourselves considering an even greater space, which includes both ultimate ends and ultimate means.

Of course, the 'mystery' which is alluded to by Daly and Farley (2011) is that the Ecological Economy is then responsible for mending the very distinction on which it is based. For instance, if spirit and matter are distinct, how do they impact each other?

We are thus left with three choices again.

The first, relativistic position is to consider consider that ends and means are both ontological categories, but also to consider contradictory points of view. This model yields two competing theories of causation from the bottom up and top down, and in which both ends of the spectrum are ‘elementary’. Mutual constraint (or mutual perturbation) cannot be considered if there is no medium for interaction. Along these lines, Daly (1998) mentions briefly the alternative stance of the naturalist and the theist. From the point of view of the theist, the naturalist suggests that means are ends in themselves, ascribing particular forms of intrinsic value. According to the theist, this would be like suggesting that an artistic medium like canvas and pastel are an end in themselves, resisting the transformation of the medium. From the point of view of the naturalist, the theist suggests that ends, such as the forms which species inhabit are simply means to an end and thus implement inappropriate controls such as putting a price on nature.

Paradoxically, the theist seems to commit the highest treason in suggesting that the determination of the ultimate end might be the product of a process which is by necessity outside of this ends/means spectrum. This ultimate distinction, like that between ‘classes and sets’ in mathematics; assumes that the ‘ultimate end’ is not part of, or a product of anything more ultimate. The naturalist, on the other hand, unwittingly enslaves an environment for the maintenance of a particular status quo. A relativist position might suggest that these two contradictory stances can be maintained; that ends and means are a purely subjective affair.

While boundaries may be subjective, viability and constraint emerge as relationship between subject and object. A second stance, the autonomous stance, is to pursue the maintenance of a system in which all components are understood to oscillate as both ends and means. This understanding of ends and means as a duality, invokes our own ability to turn extrinsic value into intrinsic value and extrinsic value into intrinsic value. It is neither prohibited to categorize an entity according to an encompassing domain, nor is an object irredeemable as merely an means to an end. As Immanuel Kant (2000) wrote, “An organized product of Nature is one in which everything is reciprocally ends and means.” We experience this firsthand in the inhabitation of and identification with our own physical embodiment. In the biological organism this is refered to as “autopoiesis”. Each element considered is a constraint. ‘Ultimate’ is understood as the limit of an iterating function, imaginary, but necessary for ‘existence’. Ethics is concerned with the establishment of opportunities for synergy and the reduced need to buffer and control an environment. In other words, when is our own ‘activity’ merely a means to an end that is no longer desirable?

In our third road, we hold tight to the notion that the distinction between ends and means is an ontological reality, and pursue foundations outside of our own experience for their differentiation. For instance, certain levels of complexity, might determine whether a system is to be treated as a mean or end, deserving of protection or perceived as resource. Alternatively, following neoclassical economics an emphasis on the human agent suggests that this mapping might be determined if we are able to discern the true nature of humans. For instance, do humans truly care for species other than themselves, or is self-interest the law? Alternatively, Daly and Farley (2011) suggest that scientific disciplines might be responsible for this assessment. To avoid circularity, this would mean suggesting that science (and thus truth?) yield appropriate determinations of value. The next sections will deal with these proposals.

3.4 The Embedded Agent

Ecological Economics emphasizes that human are embedded in nature and society. The paradox we face here is that we attempt to use the ‘real’ model of the human to distinguish the relevant features of the environment, and the real environment to distinguish the relevant features of the human. What we find is a mutual embedding. For instance, the ecosystem can be seen as transformation of the human domain; a means toward expressing the ultimate end of expressing humanity. In this way, the ecosystem plays a role in the evolution of humans. On the other hand, the human can be seen as a transformative agent toward the ultimate end of expressing the ecosystem.

For some, circularity is an epistemological problem. For instance, Birkin & Polesie (2013) critiques reflexivity suggesting that the problem we face is the result of the ‘epistemological man’, a consequence of society and humanity turning in on itself, for example in the fields of sociology, psychology and economics. In these cases, growth of knowledge is “determined by the rules and regulations internal to that science.” The proposed solution is to find a “foundation” outside of this “circular logic” (Birkin & Polesie 2013). (We do not deal largely with the relationship between social and natural sciences, in this paper, but this section suggests that they are not fundamentally different.)

When we introduce the natural sciences, uncertainty is not narrowed, and recursion is not eliminated. If we introduce the natural sciences to our conception of humans, now we must account for a billion years of evolution, which shape our perception of the environment we are basing our analysis off in the first place

(Hoffman, 2014). Our cybernetic understanding holds that any fundamental upon which we rest, changes the context in which it was perceived. The field of enactive cognition arose out of the second-order tradition which emphasizes self-organization across the brain, body and environment (Varela, 1991); the sensory-motor feedback in the production of a stable observed reality (Heinz Von Foerster, 1973); the role of affect and emotion in cognition and representation (Thompson, 2001); the linking of first and third person methodologies in neurophenomenology (Thompson, 2009); and the co-determination of self and other (Thompson, 2001). This mutual recursion between the self and other is evident in our basic biological understanding of identity. This view proposes that our own human consciousness does not sit inside our head, but instead is inherently intersubjective; it emerges as dynamic interrelation between self and other (Thompson, 2001). With this circular confrontation as a starting point, we arrive at our intersection.

A relativist perspective treats both individuals and their environment as autonomous and their aims as incoherent.

In pursuit of autonomy, we search for a limited and recursively stable set of transformations. For instance, on a deep level humans are hardwired to engage in prosocial behavior; to trust, empathize, love and perhaps even to transcend self-interest (Goodenough & Deacon, 2003; Kosfeld, Heinrichs, Zak, Fischbacher, & Fehr, 2005; L. J. Young, 2009). It is hard to imagine a discussion about ultimate ends which is distinct from these themes. On the other hand, this biological hardwiring may be one of our greatest means toward adaptation. In our evolutionary process toward well-being, this trait can either be seen as an output or input, an end or a mean, and thus participating in both our vision of the world and the inspiration for that vision. As Farley (2016) says, “It may be possible to evolve institutions that promote group cooperation on the scale necessary to solve our most serious global challenges.” (21) We can assume that the definition of serious global challenges is not independent from Farley’s own sense of empathy, socio-ecological community, and self, and that these are not distinct from his ancestor’s evolutionary coupling with the environment, or the history of serious challenges (Goodenough & Deacon, 2003).

Based on research into cognition and perception (e.g., Hoffman, 2014; Von Foerster, 1974), we find that objects of our consciousness are not just representations of an independent environment, but are perhaps better interpreted as a set of instructions for action. For instance ‘mother Earth’ is meaningful as an instruction to act with respect and appreciation or to receive care and support.

It is an inclination of ecological economists to strive for concepts less frivolous than neoclassical economists, but ultimately it seems that there remains a choice. As Jose Ortega y Gasset writes, “Man does not have a nature, but a history.” This history is a compilation of mappings of the environment on to the self. Like the distribution of cognition in the nervous system, in language and in academic disciplines, this history will come to include societal technologies with which we participate in order to map the world in terms of our possible activities.

Second-order cybernetics deals with this ethics of entanglement. Paradoxically, one can couple with their environment in proportion to the complexity of the closure of their discernment (Clarke & Hansen, 2009). This is not a far leap for ecological economists who seem to critique the narrowness of homo-economicus and monetary valuation because it is unethical, as much as it is empirically inadequate in diverse contexts. Still, after offering a wider set of contexts, in order to define it's operations Ecological Economics has to limit it's relevant contexts, and search for coherence. When we "act [ethically] so as to increase the number of choices" (von Foerster (1974) we attempt to develop redundancy amongst a variety of reference frames. This means that our selection of actions, must be consistent with the lenses through which we look, or the entities which we perceive to exist, (in equilibrium).

Our third road, again, is to search for foundations, outside of the domains which have been explored. The final distinction we will discuss regards truth, and the greater project of science.

3.5 Methodology, Ontology and Epistemology

I will preface this section with Von Foerster's (1990) philosophical question which is:

> Am I apart from the universe? That is, whenever I look I am looking as through a peephole upon an unfolding universe. Or, Am I part of the universe? That is, whenever I act, I am changing myself and the universe as well. Whenever I reflect upon these two alternatives, I am surprised again and again by the depth of the abyss that separates the two fundamentally different worlds that can be created by such choices. Whenever I speak to those who have made their decision to be either discoverers or inventors, I am impressed again and again by the fact that neither of them realizes that they have ever made that decision. Moreover, when challenged to justify their position, a conceptual framework is constructed that, it turns out, is itself the result of a decision upon an in principle undecidable question.

The discoverers movement is defined by the search for perfect and independent stability. This path from seeing to acting follows: Metaphysics → Ontology → Epistemology → Methodology. All encounters with circularity become problematic.

In Ecological Economics, characteristics of the discoverer are exemplified most strongly by Spash's (2013) realist social-ecological economists. Spash (2013) considers the possibility here to be a movement of interdisciplinary scientists. This approach is certainly not without challenges, most formidably: where to start. What initial foundation might be discovered? Conveniently, this start was undertaken formally by Spash (2012) himself who began with some ontological presuppositions, epistemological claims, methodological positions, and ideological beliefs. On what grounds should these presuppositions be decided? Here we recognize that we are entering into a discussion over the epistemological criteria for our epistemological criteria. In other words, presumably, this starting point is not subject to critique because we would have to agree to relevant ontological issues, as well as methodological and epistemological claims before we could discern on what ground critique is justified.

According to Spash (2011), one approach is to consider that axioms gain "meaningfulness to the extent that the theory as a whole is confirmed." This would suggest that ontology and epistemology are part of a larger recursive process, rather than the foundation on which elements might rest.

It may be worth noting that the founder of critical realism (suggested tentatively as a scientific framework by Spash (2011)), Roy Bhaskar, took a turn in his later years which might link to second-order cybernetics. In the 1990s, the perpetual incompleteness and possible contradictions came to be considered formally as ‘absences’ (Bhaskar, 1993), and in fact these absences gained ontological stature. In other words, invariance is constituted by the variance. Only change is continuous. In his later book “Reflections on Meta-Reality,” Bhaskar (2002) differentiates between critical realism and a “new philosophical standpoint” which breaks down previous dualities. This elicits the words of von Foerster (1972): “The logical properties of ‘invariance’ and ‘change’ are those of representations. If this is ignored, paradoxes arise.”

In the path of pure discovery, circularity and historical contingency are not acceptable. For example, in discussion of valuation, Binder & Witt (2014) write, “the preferences by which individual well-being is assessed are shaped through the very processes whose welfare effect they are supposed to evaluate.” Vatn (2005) similarly suggests that “if preferences are affected by the institutional context, one cannot base (environmental) regulations simply on an aggregate of private preferences. This would produce mere circularities.”

In practice, a pure emphasis on discovery, leads to a constant expansion of the domain. For instance, in the case of defining sustainability, distribution and scale, Malghan (2010) for the sake of formality followed Rawls (2005), alluding to the development of normative, process based rules “from behind the veil.” We can make rules for modifying the modification of the normative rules; models of socio-ecological systems which consider the models of the socio-ecological system participants (e.g., Ostrom, 2006); or models of socio-ecological systems which consider the mindsets of researchers considering the mindsets of the participants, even cybernetic ones

(Hukkinen, 2014). We can base boundaries on values, and values on science, and science on truth, and truth on epistemology, and epistemology on ontology, and ontology on metaphysics, and metaphysics on an alternative science, with alternative rules for substantiation, and perhaps we can based these rules on a prior process.

Analogous are attempts to create the foundation of mathematics by Whitehead & Russell (1910), who in their desire for objectivity, or non-self-reference, invented new hierarchies. Avoiding circularity requires constantly creating a new stable domain in which elements can rest.

On the other hand, the path of the inventor, perhaps, is analogous to Spash's (2013) critique of "environmental pragmatists" who use "a non-philosophical discourse of self-justification" emphasizing practicality, instead of theoretical rigor. These actors engage with ecosystem service valuation, natural capital, green accounting, carbon trading, and biodiversity offsets not necessarily because they think these approaches effectively represent the object of inquiry, but because they are deemed effective (by the inventor). Spash (2013) argues that: "Presenting theory as secondary to and disconnected from practice seems to misconceptualise the motives and justifications for action." Just as discoverers are left with an incompleteness, there is also a trap which is laid for inventors. Inventors leave behind them a trail which defines the way in which we engage with and access the 'world' through the communication networks, memes, models, system boundaries, institutions and technologies which they leave in their wake. They not only transform the world, the world transforms their own means of transformation. This extends the conundrum that Daly (1998) finds inherent to the development of ecological economics: "Yet we rely on marginal valuation because that is the way the market works and we want to come up with measures that are comparable to our usual economic measure of value." (184)

The question is one of linking signals to action. A price is only meaningful as a symbol for the action which it is inspires. Just as action is only meaningful in terms of change in perception.

Second-order cybernetics suggests that all systems can be mapped, (represented in terms of) a myriad number of distinctions, eg. ontology, epistemology, methodology, ends, means, agents, environments, ecosystems, and economies, inventor, discoverer. These 'mappings' are not the actual terrain (their distinctions must ultimately be mended), and thus they provide a constraint. This constraint implies that not all distinctions can be 'grasped' because they modify the conditions in which their mapping took place. A reflexive domain is a transitive set [D,D] of all mappings, of the set to itself. For instance, one mapping (eg. truth/ non-truth) may affect another mapping (ends/ means) which may affect another mapping ecosystem/ economic boundary, (which may recursively impact the process of determining truth/ non-truth, or ends/ means). A system which conceives of an external interdependence, or internal incompleteness, and thus 'steps out' in pursuit of solid ground, defines itself by this distinction, ie. the transition from one to many, and regains itself through eigenforms (coherences) ie. transition from many to one.

When we examine the positions of the discoverer and inventor closely, we may find coherence among these perspectives. Consider von Foerster's (1995) suggestion that "We become metaphysician whenever we decide upon in principle undecideable questions." (291) This decision, ('decide', from Latin, decidere "to cut off") creates the space for inquiry. We find that the discoverer is an inventor when this space is critically examined. Discoverers conceal the process beneath the structure. On the other hand, the inventor conceals the structure beneath the process; ignoring the pre-analytic vision in which they are inspired to act. We find the inventor is a discoverer, when we find that they are selecting activities and values according to a presumed environment.

These dual positions of the discoverer and the inventor are natural. To search for coherence while oscillating between modalities is the basic process of cognition and science, according to cybernetics. At each step, objects emerge as coordination across boundaries; positions which maintain the possibility of both approaches.

3.6 Conclusion

In this article we have worked through distinctions which might serve as original foundations to the field of ecological economics, including the ends-means spectrum, an embedded agent, ontology, epistemology and methodology, and the economy and ecosystem distinction. Each of these distinctions depends on recursive mapping that is described by second-order cybernetics, e.g., Environment → Economy → Environment.

Should the project of Ecological Economics be driven toward balance of a narrow set of actions involving ecological and economic actors, or should it include an expanded repertoire of behavioral considerations, separate systems of valuation, science at large and philosophers of science? Who or what should determine this boundary? How many controls are necessary for the economy to become itself? What context does Ecological Economics transform? When we consider elements to be within our domain (or in our environment) we ascribe them agency, or autonomy. We empower them to sever a possibility space, we accept the results of this severance and modify our actions accordingly.

The epistemological lenses through which we look, which might be pragmatist, empiricist, realist and idealist in nature, exemplified by various forms of Ecological Economics, themselves represent eigenrelations. This is not ‘ontological feedback, but feedback amongst the various perspectives we might take in relating to our world. The treatment of the system from one perspective necessitates the treatment of the system from another.

In this sense, foundations occur, paradoxically, when they are relinquished. Boundaries are enacted by connecting transformations in a circular process. In this, each element is both an operator and an operand; inhabiting a structure which accounts for a variety of potential (temporary) states. The system at each level responds to its environment, only through linking its own operations. Operations are linked when actions are treated as signals for other actions. That cybernetic control, matter, order, truth, and experience are coarising points to the emergence of a heterarchy within Ecological Economics.

Cybernetic systems implement controls so as to minimize ‘information’ or variation within their ‘subsystems’. This results in information waste expressed ultimately as loss of energy. Overcoming this mutual drive for control across disciplinary boundaries or boundaries of other sorts involves re-engaging with circularity in pursuit of eigenforms; or coherences across distinctions.

This article creates a space by considering the distinction between relativism and hierarchy (from hieros “sacred” and arkhia “rule”), suggesting that both are a consequence of the other. Instead of allowing these two sides to cancel each other out, embrace of this paradox promotes a transition toward ethics as systems seek redundancy in order to relax unnecessary controls on their environment and yet maintain their viability. As Mabsout (2015) suggests, reflecting on a non-anthropocentric conception of humanity's place in the ecosphere, "letting go of the illusion of a fixed inner self goes hand in hand with warmth and universal compassion." That this is experienced on the far side of contradiction suggests that there is a deeper reality in the boundary between the real and the imaginary, a deeper humanity in the boundary between humanity and its environment, and perhaps a deeper Ecological Economics in the boundary between what is Ecological Economics and what is not.

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CHAPTER 4: GROWING CLOSE TO HOMEOSTASIS

4.1. Introduction

Perhaps the most serious challenge currently faced by society is the conflict between global food security and environmental sustainability. Globally, about 840 million people are chronically hungry, (FAO, 2013), 2 billion suffer micronutrient deficiencies (Tulchinsky, 2010), and 1.9 billion are overweight or obese (WHO, 2014). Though food production has largely kept pace with population growth on the global scale, in many countries, excessive population growth is increasing the absolute number of malnourished people (Marsh, 2017). Demand for food is highly inelastic, which means that small decreases in supply lead to large increases in price, dramatically decreasing access for the poor and potentially causing a surge in global malnutrition as happened during the food crisis of 2007-8 and 2011-12 (Farley et al., 2015). The FAO projects that failure to increase global food production by 70% by mid-century in response to population growth and rising affluence will have unacceptable humanitarian and social costs (FAO, 2011). Undernutrition is a factor in nearly half of all deaths of children under five (UNICEF) and those who survive may be developmentally impaired. Food shortages also contribute to political unrest. For instance, in 2008, climate change induced droughts and rising food prices led to food riots in dozens of countries around the world (Homer-Dixon et al. 2015; Berazneva & Lee, 2013). Kelley et al. (2015) connect climate change, fresh water use, and crop failure to the current Syrian civil war.

Even at current levels of production, however, food systems are among the greatest threats to global ecosystems. Rockstrom et al. (Rockstrom et al., 2009) identify nine planetary boundaries that we cannot exceed without imposing unacceptable ecological costs. Food systems are the leading threat to four of these boundaries: biodiversity loss, nitrogen and phosphorous emissions, land use change and freshwater use. The most abundant terrestrial vertebrate on the planet is now the chicken (FAO), and the biomass of cattle alone is more than 16 times the biomass of all wild terrestrial vertebrates, whose biomass has fallen by half in the last 100 years alone (Smil, 2013). Nitrogen and phosphorous are essential to agricultural production and increasing yields, but their emissions pose major threats to marine and freshwater systems. Food production now covers almost 40% of the global land surface (World Bank, 2016), and the marginal ecological costs of converting even more land to agriculture are almost certainly rising. Agriculture is also a major threat to the remaining planetary boundaries, especially chemical pollution and climate change. The food system currently contributes 30% of global GHG emissions (Garnett, 2011). Among the expected ecological costs of exceeding these boundaries are the degradation and loss of ecosystem services essential to agriculture (eg. Davidson, et al., 2006; Altieri et al., 2015, Craine et al., 2010).

Proposed solutions to the conflict between agriculture and biodiversity are loosely captured by the sparing vs. sharing debate. Should we engage in input intensive, highly productive agriculture on less land in order to set aside the remaining land for conservation (sparing) (Phalan et al., 2011a; Phalan et al., 2011b), or promote agricultural practices compatible with high biodiversity and healthy ecosystems (sharing), even if it requires more land (Fischer et al., 2011; Tscharntke et al., 2012a)?

Addressing this conflict may be less difficult than it appears for several reasons.

First, the sparing vs. sharing debate may be inappropriate: it appears possible to dramatically improve agricultural output while simultaneously increasing biodiversity and ecosystem services, especially on the small-holder properties in developing countries that produce the bulk of the global food supply (Clough et al., 2011; Kremen, 2015; Pretty et al., 2005). Second, the world produces more than enough food to feed everyone if it were distributed more equitably, and far more than enough for a healthy, primarily plant-based diet. Third, an estimated 40% of global food production is wasted, typically rotting before it reaches consumers in poor countries, or thrown in the garbage by consumers in rich ones (Gunders, 2012; Gustavsson, 2011). Fourth, 33% of global soils are moderately to highly degraded, reducing their productivity (FAO, 2013). Part of this degradation results from the loss of 50-70% the soils' original pre-agricultural carbon stock (Henderson et al. 2015). Restoring soil carbon can therefore help increase agricultural production while helping to mitigate climate change (Lal, 2010a; Lal, 2010b). Finally, the largest irrigated crop in the US, and a major crop in other wealthy nations, is lawn grass, a chemical intensive monocrop, typically maintained with heavily polluting lawnmowers (Milesi et al, 2015). Replacing lawns with low input, biodiverse food gardens offers an opportunity for sparing and sharing simultaneously.

The goal of this paper is to assess the potential for society to feed itself without exceeding ecological limits, emphasizing local production. To simplify the analysis, we focus on a single foodshed—Chittenden County, Vermont; and emphasize a single planetary boundary—carbon emissions. However, we also consider land use change, phosphate and nitrogen emissions, and chemical pollution by prioritizing local organic food production on land suitable for agriculture (including lawns). Furthermore, we assume that people are more likely to mitigate the ecological impacts of their consumption habits when production takes place within the community. To achieve our goal, we use GIS to estimate suitable agricultural land in Chittenden county. We derive estimates of the nutritional content and associated carbon emissions of agricultural commodities from the literature, and develop a linear programming model to minimize carbon emissions from different diets (standard American, USDA recommended omnivore diet, and USDA recommended vegan diet plus milk products) subject to meeting basic nutritional needs.

The paper as organized as follows. Section two provides an overview of similar studies. Section three describes our methods in detail. Section four provides results and discussions. We end the paper with a summary and our conclusions.

4.2 Literature Review

According to most climate scientists, atmospheric carbon stocks must be held to 350 ppm to 450 ppm of CO2e to avoid catastrophic climate change (Hansen et al., 2008; IPCC, 2014; Rockström et al., 2009). This in turn will require reductions in GHG emissions by 80-95% below 1990 levels by the year 2050, en route to zero emissions (IPCC, 2007, IPCC, 2014).

While targets are clear, the approach for meeting targets is extremely complex and this complexity is at odds with the current uniformity in the food system. At almost each stage in the modern food system, four firms control more than 40% of the market (Howard et al., 2016). These powerful actors are able to drive innovation, supply chain dynamics, prices, and policies, which define the direction we take; this again allows powerful actors to define the problem space and drive innovation accordingly. As Ison & Russell (2007) say *"It would seem that the number of scientists and engineers rarely exceeds .6% of the workforce, yet the practices which they largely initiate, give rise to technologies, metaphors, 'facts', and forms of organization..." (2)*

At its worst, mainstream debate over the direction of the food system is framed in simple dynamics, namely, the splitting of immense varieties of farming methods and products (Vasseur et al., 2012) into categories of organic and conventional, (Chang, 2012) and analysis of the effect on single dimensions such as yield per acre (eg. Seufert et al., 2012) which mirrors a sharing vs. sparing debate focused on land available for forest cover (Balmford et al., 2005) devoid of local context, and remaining inconclusive with regard to health impacts (Benbrook, 2012). Oversimplification does not do justice to the range of production approaches or social, ecological and health concerns, (Benbrook, 2012; Campbell et al., 2014; Fischer et al., 2014; Snedeker & Hay, 2012; Soga et al., 2014; Wood et al., 2015) and naturally narrows the solution space. Improving productivity is generally the agri-business response to mitigating greenhouse gases. By improving yield per acre, land can be spared for forest or other purposes (Davies et al., 2009; Godfray et al., 2010; World Bank, 2009); World Bank, 2009; Godfray et al., 2010).

In addition to supply chain solutions, additional research has looked at consumer choice. For instance, Peters et al. (2016) conducted an analysis of various diets that we might possibly produce within the United States, and the associated carrying capacity. This research tends to emphasize the benefits of reducing meat consumption (Garnett, 2011), but gives little attention to positive feedbacks that occur with constraint, such as increased input demands for crop production on marginal lands.

Researchers who engage with the particularity of such feedbacks and relationships, tend to focus on developing institutions which promote local solutions to what are often global problems. (Reilly & Willenbockel, 2010, Rammel et al., 2007, Provenza, et al., 2015).

The "foodshed" approach tends to emphasize local food production. Examples of food shed inquiries include San Francisco, (Edward Thompson, Harper, & Kraus, 2008) which analyzed the possibility for a purely local diet. British Columbia (British Columbia, 2006) analyzed how much production would need to increase to account for growing population. Massachusetts (Holm, 2001), conducted assessments to determine their self-sufficiency. Research in New York (Jackson et al., 2001) analyzed the smallest spatial foodsheds that could provide food for every population center in the state and later Peters et al. (2007) mapped carrying capacity with as assessment of a 'complete diet model', while Plunz et al., (2012) researched capacity for urban agriculture in New York City. In Shelburne Falls, Massachusetts (Dunbar, Hoffmeier, & Rhodes, 2009) has analyzed food security with a particular focus on open spaces and backyard gardens. Thus far, 'foodshed' analysis has focused predominantly on capacity and food security. There is an opportunity for this level of analysis to enter discussions on biophysical efficiency, and food system interaction with planetary boundaries.

When we consider problems and solutions at the foodshed scale, two important changes are apparent. First, the variety of potential actions expands immensely with coordination among producers, citizens, consumers, financiers, regulators and researchers. Second, the interaction of real constraints yield nonlinear results and so debates over optimality and efficiency become rooted in a particular reality.

Starting with a vision and moving backward may be an appropriate approach for engaging with complexity (Jaros & Cloete, 2010). The foodshed movement which we will call ‘foodtopia’ is perceived to be part of a larger shift. As industrialized nations have rapidly diminishing marginal benefits from increased economic growth (Daly and Farley, 2011), we can imagine ‘foodtopia’ as a vision which puts ecologically sound food production at the center of the post-growth society. Foodtopia provides some direction for post-growth society which is increasingly afflicted by diet related disease. Recently the Deputy Mayor of New York City and Health Commissioner launched a program called ‘Fruit and Vegetable Prescription Program’ allowing obese and overweight patients to use “Health bucks” at local farmers’ markets (NYC Health, 2017). This process should start with biophysical constraints which are not flexible (ie. human health and earth systems) and move toward social constraints (eg. economics) which can be adapted to produce optimal outcomes (Daly and Farley, 2011).

4.3. Methods

4.3.1. Location

Chittenden County, spanning 619 square miles, population 160,000, rests alongside Lake Champlain in Northern Vermont. It is home to Burlington, Vermont’s largest city, generally considered a progressive college town. The progressive vision of Burlington and its local food scene are generally supported by the surrounding towns, which are some of the wealthiest in the state (McKellips, 2009). The region prides itself on local food, though statistics are (as far as I know) unavailable.

Vermont has dedicated sufficient acreage to meet fruit needs and dairy needs (by a factor of five) but falls short in the case of vegetables and protein (according to USDA categorization) by 28% and 91% respectively (Conner et al., 2012). McKellips (2008) estimates that in the 6 county region surrounding and including Chittenden, demand could be met by adding 572 hectares for vegetable production, 2064 ha for wheat, and 11,509ha for fodder crops. On the other hand, dairy and apples are major exports. Dan Erickson, researcher at the food systems institute, mapped land which is available for agriculture in the county (Erickson, 2011) and in (Erickson, 2013) found an overwhelming resident willingness to participate in using their land for agriculture, both in suburban areas and on big non-farm lots whether for compensation or good will.

Vermont is extremely affluent by global standards. Nonetheless, 11.4% of households (12th lowest among US states) (USDA 2017) and 21% of children are food insecure, while 25% of adults are obese (the 9th lowest rate among US states). Over 40% of the US population had inadequate intakes of vitamin A, vitamin C, vitamin D, vitamin E, calcium, and magnesium, with worse deficiencies among the overweight and obese (Agarwal et al., 2015). An estimated 76% of Americans failed to meet intake recommendations for fruits, and 89% failed to meet them for vegetables, two important sources of micronutrients (Moore and Thompson, 2015) One important factor is the high price for fruits and vegetables relative to heavily subsidized, energy dense foods (Alston et al., 2008; Franck et al., 2013).

This analysis considers the land available, food production, and diet selection.

4.3.2. Land Availability

In order to assess land availability, this study divides land into three categories; urban, rural and "imported" (i.e. land used to grow imported food). We assume no land constraint for imported food. Current estimates for urban and local food are based on Dan Erickson's (2013) assessment of available land within Chittenden County. This study found that there are 3,346 hectares of urban agricultural opportunities with prime soil on nearly level ground and roughly 25,000 available hectares outside of residential areas, within Chittenden County. (Erickson, 2013), For this initial model, we applied constraints of 3,300 urban hectares, and F23,000 rural hectares. Our model includes the possibility that tree crops can be grown in riparian areas, as well as in pastures; and even experimentally, in the careful replacement of new growth forest with climax species.

4.3.3. Diets

Defining nutrition in the case of food security is complex; and this complexity matters, particularly in the long term. Nutrient requirements vary with each physiologically unique individual and the diet history of this individual. Modern science is only at the very beginning of linking food habits and preferences, bioaccessibility (the breaking down of nutrients), bioavailability (the ingestion of nutrients), and bioefficacy (the effective use of nutrients) (Holst and Williamson, 2015). In other words; a particular nutrient is not just a building block; each nutrient modifies food preferences, as well as the ability to break down, digest, and effectively use nutrients. These differences might mark the distinction between an essential nutrient and a toxin for a particular context (eg. phytochemicals and antioxidants).

These interactions vary, not only in the short term, but in the long term. For instance; a recent article (Sonnenburg et al., 2016) published in Nature, called, "Diet-induced extinctions in the gut microbiota compound over generations" talks about the hidden long term effects that a diet can have. Scientists estimate that modern city dwellers in the Western world have irreversibly and dramatically reduced the complexity of the gut microbiome (Yatsunenko et al., 2012). Further, we are rapidly losing flavor feedback mechanisms which link flavors, preferences and physiological needs and which serve as biological signals for the coordination of functions which break down, and absorb nutrients. This linking and learning is impaired when we eat flavored, processed and enhanced foods (Provenza, Meuret, & Gregorini, 2015), and can lead to overeating, when deficiencies cause food cravings, but we have lost discernment over what precisely our body needs. Approaches to feeding livestock have provided an empirical arena for this study of dietary preference, discernment and diet eg. (Atwood, Provenza, Wiedmeier, & Banner, 2001); and in humans this research is emerging in the gut-brain connection (Mayer, 2011). We are coming to find that pain and pleasure are associated with eating that which is healthy in accordance with a variety of homeostatic states achieved in utero and in development. (Mayer, 2011) Thus, we find an entanglement of feedbacks among food quality, overeating, health, physiological needs, food production, scarce resources, ecosystem function, and economies.

It is in the context of this complexity that nutrients and the risk of novel technologies should be measured. For example, conventional agriculture may contribute to depleted nutrient density in modern crops (Davis, Epp, & Riordan, 2004; Marriot & Wander, 2006; P. J. White & Broadley, 2005), particularly phytochemicals, (Davis et al., 2004) and wariness of increasing influence of technologies in the globalized supply chain. The modern supply chain increasingly relies on nano-technologies or increasing efficiency in agricultural production, food processing and enhancement, food conservation, packaging, and delivery. Some recent studies point toward possible toxicological effects on biological systems. (Amini, Gilaki, & Karchani, 2014; Nel et al., 2009; Scheringer, 2008) and as science progresses we find new impacts of old technologies, such as science linking obesity, diabetes, environmental chemicals and gut biota (Snedeker & Hay, 2012).

The good news is that agricultural science has become increasingly knowledgeable about the factors which lead to healthy soils and nutrient uptake in plants, (FAO, 2015), in particular the fostering of healthy coupling of plants with soil microorganisms, (Berendsen, Pieterse, & Bakker, 2012; Bulgarelli, Schlaeppi, Spaepen, Ver Loren van Themaat, & Schulze-Lefert, 2013) and the impact of inputs and soil structure on microbial habitat (Young & Crawford, 2004), and the effect of plant species (Hobbie, 1992).

We approach food security at the food-group level with the strong provision that food is grown and delivered in a way in which the necessary nutrient levels, and human and livestock physiological characteristics are sustained. Further, food grown in urban areas must not put people at chemical risk. The diets we consider are the average American diet, the recommended diet, and the recommended lacto-vegan diet, as recommended by the USDA (2010). Sub-components of these diets are broken into categories of: fruits, vegetables, grains, proteins, and dairy. Within these groups are subcategories such as ‘dark green vegetables’, ‘meat, poultry, eggs’ and ‘Nuts and

Seeds'. The USDA (2010) gives recommended daily portions for each sub food-group made explicit in a later section. The emissions and yields associated with each category of food is dealt with in the following section.

4.3.4. Yields

A number of studies have estimated average yields for small scale vegetable production. Rabin et al. (2012) and (Stoner & Smith, 1978) both estimate .5 pounds per square foot. A poll done by the National Gardening Association (2009) and a study by the Penn Center Public Health (Vitiello, Nairn, Grisso, & Swistak, 2010), (Jett, 2012) estimate .3-.75lb per square foot. A New York City crowd-sourced study (Gittleman, Jordan, & Brelsford, 2012) estimated .33-1.2 lbs. per square foot. All of these estimates are conservative when compared with biointensive approaches, which can yield at least .95 pounds per square foot (Jeavons, 2006). Given harsher environmental conditions in Vermont, we conservatively estimate that biointensive methods can yield 0.5 pound/ft^2 on average. This information was supplemented with the following sources which give approximate yields for alternative fruits, vegetables and nuts. (Barney & Miles, 2007; Myers & Meinke, n.d.; NASS, 2008; "USDA/NASS 2014 State Agriculture Overview for Vermont," n.d.; USDA, 2012) (Barney & Miles, 2007; Demchak, Harper, Kime, & Lantz, 2012; Julian, Seavert, & Olsen, 2008; Lackman, n.d.; Mckellips, n.d.; Myers & Meinke, n.d.; NASS, 2008; Service, n.d.; USDA, 2012; Wahl, 2002)

We model a scenario in which locally managed fruits and vegetables are grown under an intensive organic regime (also known as ecological or sustainable intensification (Bommarco et al., 2013; Caron et al., 2014; Doré et al., 2011; Tittonell, 2014; Tscharntke et al., 2012b), meaning that research and farmers work together to manage ecological services, soil health and yields. We focus on this method of production for a few reasons. The first reason regards autonomy. Research within the fields of political ecology (Forsyth, 2003; Robbins, 2012), food sovereignty, (Nicholson, 2011; Wittman, 2009) and agricultural innovation systems (Rolling et al., 2012) explore relationships between power, technology, and adaptation. Much of this discussion has revolved around small-holder agriculture in developing nations, but may be meaningful in the context of developed nations who aim to orient food systems beyond profit. If we are to claim autonomy over the method of production within the region, we cannot be dependent on the changing infrastructure, crop choices and inputs developed by agri-business to maintain conventional production. Globally, the food sovereignty movement envisions local, yet interdependent food systems (Akram-Lodhi, 2013). It is worth noting the greater option value of organic agriculture: converting from organic to conventional agriculture is quite simple, but the impacts of conventional practices on ecological infrastructure such as pollinator loss, degraded soil conditions and loss of genetic and phenotypic variety means that moving in the other direction can be very difficult (Taleb, 2012). The second reason has to do with nutrition discussed previously. Third and most plainly, if agriculture is to be sustainable, it cannot rely on non-renewable inputs, or cause irreparable harm to ecosystems. Intensification and substitution within conventional agriculture correlates with a loss in soil structure and biome, with a resulting loss in water retention capacity, aeration, nutrient and water storage, natural predators, pollinators, and agrobiodiversity (Turner et al, 2011). Conventional agriculture is a leading threat to climate stability as well as major driver of deforestation, water and air pollution, biodiversity loss, and depletion of soils and freshwater resources (Foley et al., 2005, Nakicenovik et al., 2000, Tilman et al., 2001 and Vitousek et al., 1997, Rockstrom et al., 2009). Finally in urban areas agro-ecological approaches will ensure that there is no toxicological threat to residents, and other urban creatures.

Nut trees can be grown in Vermont to sequester carbon and provide important nutrients. Yields were calculated using estimates from (Perry, n.d.). While most nut trees are best with freeze free periods of 150 days per year, historically, Vermont's is 147. The Vermont Climate Assessment (Galford et al., 2016) suggests that climate trends will accommodate trees in this range. Yields are expected to fluctuate and are unlikely to be profitable under current market conditions, but further research and variety development can improve hardiness and viability. While yields vary, we estimate conservatively that nut trees will produce ½ lb. per square meter.

Estimates for meat and dairy yields were based on Mckellips, (2010). Estimates for poultry and meat yields are not high, as locally raised animals are expected to have the capacity to live healthy lives and graze without GHG intensive intervention. Co-products were considered independently, which means that with synergies this data represents an overestimate of emissions. Breeding requirements were ignored, yielding an underestimate, and land required for feed was internalized in yield per hectare estimates. Carcass weight estimates were normalized for consistency with GHG emission data based on these units.

Post farm gate waste estimates are consistent with national averages per food item, based on the Loss Adjusted Food Availability (LAFA) data series (USDA ERS,

2012) following Heller & Keoleian (Heller & Keoleian, 2014). This loss adjusted data series takes into account losses at the farm level, retail level and consumer level. These waste estimates are initially held constant, though further in the analysis they are subject to improvement. For local urban and rural agriculture, our model estimates that with changed consumer's perception, we can reduce production losses. We estimate that foods grown in one's own garden or provided in a CSA model, will not be subject to the scrutiny of the supermarket consumer aesthetic. Further, in direct-to-consumer production, there are no distribution and retail losses. However, we also estimate that these losses are offset by storage and production losses required for off-season consumption. Thus; all waste estimates remain unchanged.

Table 2 Yield and Waste Estimates

Food Item	Edible Yield (kg/ hectare)	Post-waste percentage consumed
Fruit (General)	24,412	40%
Vegetables (General)	24,412	52%
Beans and Peas (General)	24,412	90%
Apples	35,000	50%
Potatoes	18,000	52%
Beans	24,412	90%
Beets (for sugar)	48,824	50%
Soybeans (for oil)	24,400	50%
Grains	5,000	69%
Milk	8,900	68%
Cheese	890	73%
Pork	300	72%

Chicken	350	78%
Eggs	360	60%
Beef	120	72%
Nuts	5000	50%

Note. Yield and waste estimates for various food types derived from literature review and calculation described in methods.

4.3.5. GHG emissions

While some sources of GHG emissions are easily quantifiable and predictable, emissions in agricultural production are much more difficult to control and predict. Soil, in its immense complexity, has been referred to as the “final frontier” in science (McNeill & Winiwarter, 2004; Schneider, Kallis, & Martinez-Alier, 2010). Our understanding of GHG flux is complicated by the contexts of soil-plant interaction, (eg. rhizosphere microbiome (Berendsen et al., 2012)), production practices (Gianfreda, Antonietta Rao, Piotrowska, Palumbo, & Colombo, 2005; Marriot & Wander, 2006; Oleszczuk et al., 2014), agro-biodiversity ((eg. pollination, and pest management (M. Altieri & Nicholls, 2004) (L. Jackson et al., 2010), considering offsets and net productivity (Tilman, Hill, & Lehman, 2006)), landscapes, (Viaud, Angers, & Walter, 2010) and changing climates (Craine, Fierer, & McLauchlan, 2010; Davidson & Janssens, 2006; Sitch et al., 2008). Our uncertainty is again complicated by sensitivity to analytical boundaries, (Phillips, 1998) spatial dimensions (Post et al., 2007; Yoo, Amundson, Heimsath, & Dietrich, 2005) and temporal dimensions (Fontaine et al., 2007; Krull et al., 2003), and our ability to measure (Stockmann et al., 2013). Lastly, tying together human systems with these processes makes control a very difficult proposition as soil dynamics vary with socio-economic conditions, eg. (Lal, 2004) and knowledge transfer (Bouma, Van Altvorst, Eweg, Smeets, & van Latesteijn, 2011). Meanwhile decomposition processes (Craine et al., 2010) and the digestion processes in humans and animals are also a frontier of their own (Holst & Williamson, 2008; Provenza et al., 2015; Villalba & Provenza, 2009). Each of the above 'conversations' are subject to dispute, contradiction, and interaction effects (Stockmann et al., 2013). Sophisticated process models which could potentially be adapted to correlate crops, inputs and management with GHG flux, include below ground processes such as soil water, aggregate structures, microbial biomass, and humus (eg. (Malamoud, Mcbratney, Minasny, & Field, 2009; Parton, 1996)). Without this level of analysis, it can be misleading to assume that certain farming systems and incentive structures will be preferable in a complex socio-ecological system. Social complexity, management, and long term soil stability aside, associating particular management techniques with below ground carbon stocks remains difficult (Karlsson, Andren, Katterer, & Mattsson, 2003; Luo, Wang, & Sun, 2010). Lastly, at this point most models focus on large scale systems and staple crops. This complexity absolutely does not mean that it is impossible to sequester nutrients and mitigate climate change in agricultural production, or that this process cannot be modelled. To the contrary, efforts to build soil structure and regenerate nature's infrastructure are essential for halting positive feedbacks which reduce ecological functions and require further substitution for these functions. Instead, this complexity is an indicator that mitigation in agriculture is unlikely to emerge through the same centralized incentive structures, command and control policies, and centralized technology developments that are appropriate in other sectors or stages of the supply chain. A new 'unit' of analysis is required. We suggest that this unit is a coupled human and natural system, in which mitigation efforts can be measured against their impact on the entire coupled human and natural system, rather than on a narrow ecological or social impact. Since this paper is not aimed at identifying emissions associated with particular practices, or methods, but is interested in identifying mitigation potential across general dietary and production approaches, we use data from a set of meta-analyses to derive estimates for a climate-friendly approach and a conventional approach. For fruits and vegetables, we use a meta-analysis done by Heller and Keoleian (2014) of global life cycle assessments. In the context of local production, results seem to overestimate emissions from vegetable and fruit production, because they account for some exotic cases, but using a consistent data source was determined to be the best course of action. While average vegetable production was estimated to be .33 kg CO2e/kg fruit, many peer-reviewed life cycle analyses, demonstrate the possibility of producing vegetables, fruits and grains, far under this level; ranging from -.24kg/kg (yes, negative) to .2kg/kg (eg. Koerber et al. 2009; Tzilivakis et al. 2004; O'Halloran et al. 2008; Mason et al. 2002; Van Hauwermeiren et al. 2007; Fogelberg & Carlsson-Kanyama 2006), even when including processing and transport, (Pathak, Jain, Bhatia, Patel, & Aggarwal, 2010)). We made the assumption that using the correct suite of management approaches, and adaptive institutions we would be able to reduce GHG emissions across all local, organic produce, relative to conventional agriculture, by a conservative, 40%. This is roughly consistent with Niggli et al., (2009), which focuses on organic management practices, but is not intended to suggest that a particular management choice will produce this outcome.

For the production of dairy, eggs, poultry, pork, and beef, an FAO study titled

“Tackling Climate Change Through Livestock”, (Gerber et al., 2013) provided estimates on production emissions for the U.S. This document contains information regarding potential reductions by offering a distribution of emissions “within geographical regions”. Assuming intense local mitigation effort, we estimate conservatively that we can achieve reductions consistent with the bottom 10th percentile emission level. In most cases this is between a 30%-40% reduction from average emissions. Some studies such as (Vuichard et al., 2007) point toward the possibility of having a negative net flux, eg. more than 100% mitigation, but this is subject to uncertainty over time; and we hope that more clarity emerges with ongoing research. For instance, a local farmer, Abe Collins, has had success, not with conventional tilling, but by using a mechanized spade which allows manure to infiltrate beneath the surface, and sees increases of inches of topsoil per year (Kittredge, 2014; Seidl, 2009), which may yield 100% mitigation or much more depending on nitrogen and methane flux. If the capacity to measure flux increases, this may be an exciting possibility which we do not consider in this paper.

Transportation emissions within the food system are perhaps less important than many people believe (Defra, 2008), comprising 8-12% of food system emissions depending on estimates (Garnett, 2011). There are ways to reduce GHG emissions in transportation by shifting to more efficient modes of transport, reducing distance of transport through consuming locally or technologies which increase route efficiency, and through systemic efficiency increases like vehicle sharing (Garnett, 2011). Generally however, local food is not necessarily superior and can even be more emission intensive (Edwards-Jones et al., 2008). Of course, these aspects depend on food type, which have varying needs such as refrigeration. Further one could consider the manner in which economies of scale are influenced by infrastructure. By generating a new way of organizing and optimizing transportation; it is possible for local food to be much less GHG intensive. For instance, work-place delivered CSAs offer a way to reduce redundancy in transport. Through input-output life cycle analysis, Weber and Matthews (2008) find the following transport emission to total emission ratios: red meat transport emissions 1:12, fruit and vegetable: 1:4, dairy: 1:15, grains: 1:5, other 1:5, chicken/fish/eggs: 1:7 Based on (Weber & Matthews, 2008) These estimates are generally consistent with the broader literature, and sufficient for the level of granularity at which this study operates.

In the case of Urban Agriculture, estimates which do not consider sequestration and the offset of lawn maintenance tend to discover around an 80-90% reduction from conventional supply chains (eg. Kulak et al., 2013). The EPA estimates that one hour of mowing the lawn is roughly equal to driving 11 cars for one hour. When considering the potential for carbon sequestration, and reduction of intense emissions from lawn maintenance we have decided to consider Urban agriculture emissions net neutral.

Table 3 Emission Estimates

Food Item	GHG emissions for imported foods (kg/kg)	Local, Agroecological grown, associated GHG emissions (kg/kg)	Urban Emissions
Fruit (General)	.36	.216	0
Vegetables (General)	.33	.198	0
Grains (General)	.49	.29	0

Beans and Peas	.78	.468	0
Bananas	.97	N/A	N/A
Oranges	.97	N/A	N/A
Orange Juice	.36	N/A	N/A
Peanuts	.78	N/A	N/A
Fish	2.9	N/A	N/A
Apples	.36	.36	N/A
beets	.73	.438	0
Potatoes	.33	.198	0
Soybeans (for oil)	.73	.438	.438
Milk	1.75	1.1375	N/A
Cheese	8.377	5.445	N/A
Eggs	2.9	1.682	N/A
Chicken	4.4	2.948	N/A
Turkey	7	4.69	N/A
Pork	4.6	3.726	N/A
Beef	30	20.7	N/A
Nuts	N/A	0 (riparian areas)	0 (riparian areas)

Note. Soybeans are grown for oil, and must be processed, and thus gain no advantage from being grown in urban areas.

4.3.6. Estimating baseline food grown locally

The baseline for greenhouse gas emissions in the region was determined by the average U.S. diet, (Heller and Keoleian, 2014). The emission estimates used are adjusted for waste of approximately 40% including production, postharvest, processing, distribution and consumer loss (FAO, 2011). It is important to consider a few reasons why this is likely an underestimate of actual emissions. First of all, this accounts for whole foods, which do not include the processing emissions associated with combining foods for novel products. Second, this assumes that the current diet is comprised of foods that can be grown locally. For instance, we excluded a separate analysis of the impact of eating tropical fruit and other foreign foods.

In order to discover an optimal scenario we used a linear optimization. Within the model, we allowed an optimization to determine how much of each crop should be produced and consumed. An optimal outcome is one which minimizes GHG emissions. Within the model we applied a constraint on land availability according to the determination discussed previously, and also a constraint such that diet requirements were satisfied.

Objective:

Minimize total GHG emissions for different dietary options for Chittenden county, where emissons are determined by food quantities multiplied by associated import, rural or urban emissions.

$$\text{Minimize } f(x_{u1}, x_{u2} \ldots x_{r1}, x_{r2} \ldots x_{c1}, x_{c2} \ldots) = \sum_i^n (c_{ui}x_{ui} + c_{ri}x_{ri} + c_{ai}x_{ai})$$

Subject to

$$0 \leq \sum_i^n a_i\, x_{ui} \leq A_u$$

$$0 \leq \sum_i^n a_i\, x_{ri} \leq A_r$$

$$DR_k \leq \sum_i^n (x_{ui} + x_{ri} + x_{ci})$$

$x_i \geq 0$ (i.e. negative output is not allowed)

Where:

$f(x_1, x_2, x_3\ldots)$ is the GHG emission function for food groups (the objective function);

c_i denotes GHG emissions from food group i, and x_i denotes food group i;

x_u denotes urban agriculture, x_r denotes rural agriculture and x_c denotes conventional, imported agriculture;

$\mathrm{A_u}$ denotes available urban land in the Chittenden County food shed, $while\ A_r$ denotes available rural land in the Chittenden county food shed;

A_r=rural, non-residential agricultural land area available in Chittenden county (25,000 ha)

A_u = urban (defined by determination of residential area) agricultural land area available in Chittenden county (3,300 ha);

a_i = land area required to produce one unit of crop i

DR_k = dietary requirements according to three regimes (standard American diet, recommended vegan and recommended omnivore) denoted by k

Dietary Specifics:

Three diet options were considered: Current U.S. Diet, Recommended Vegan and omnivore as defined by (Heller & Keoleian, 2014), following (USDA, 2010). Diets were defined by food group servings per day. An alternative approach would have been to define the recommended diet by nutrients rather than servings. Optimization in this case would identify the lowest possible carbon emissions for a healthy diet, and it is very likely that the results would be quite similar to the results found for the vegan diet.

Current US diet per capita per day:

Fruit: .19 kg., vegetables: .38 kg., grains: .21 kg., beef: .054 kg., pork: .037 kg., poultry: .068 kg., eggs: .014 kg., nuts and seeds: .024 kg., dairy: .35 liters, oils: 46.2 grams

The Recommended Omnivore Diet per capita per day:

Fruit: .47kg, vegetables: .59kg, grains: .17 kg, beef: .031kg., pork: .023kg., poultry: .04kg., eggs: .085 kg., nuts and seeds: .02 kg., dairy .71 liter., oils: 33 g

The Recommended Vegan Diet per capita per day:

Fruit: .47kg., vegetable: .59 kg., grains: .2 kg , additional beans and peas: .054 kg, grains: .17 kg, oils 19 g, nuts and seeds .059 kg.

Only vegetables, fruits, beans and peas were allowed to be grown in urban areas.

The linear optimization was done on Excel, using the solver function. For each diet, emissions were minimized by changing *where* food was grown rather than *what* food was grown.

4.4. Results

Baseline emissions:

Based on (Heller & Keoleian, 2014) with a slight increase for processing, our baseline estimation considering the Chittenden County population and 365 days in a year is approximately, 300,000 metric tons of CO_2e per year.

Table 4 Locally Grown, Standard American Diet

Food Category	Land Allocation with Waste	GHG emissions with Waste (Metric tons)	Land Allocation with no waste	GHG emissions with no waste
Grown in Urban Areas				
Fruit	1,136	0	455	0
Vegetables	1,748	0	909	0
Grown in Rural Areas				
Beef	20,017	49,721	21,900	54,401
Dairy (Milk)	3,377	34,192	2,297	23,250
Soybean	1,606	16,882	803	8,441
Imported	(Land N/A)			
Eggs	3,785	39,517	2,271	23,710
Chicken	14,546	22,402	11,346	17,473
Pork	10,004	13,805	7,202	9,940
Beef	16,483	59,340	4,380	15,767
Dairy	3,377	34,192	0	0
Grown in Riparian Areas				
Nuts and Seeds	561	0	280	0
Total		209,003		137,652

Note. This excludes foreign foods and considers current diet in whole foods; Eg. Beets not sugar derived from beets, and thus represents an underestimate against real current diet.

According to the optimization, 56 hectares of potatoes, 20 hectares of beans, 117 hectares of beets and 304 hectares of soybeans were grown in urban areas. Note that this only utilizes about 20% of the available urban hectares; even assuming that beets and soybeans can be processed for sugar and oil. This is simply because our model does not allow for any of the other main food groups to be grown in urban areas eg. exotic fruit or beef. The model resulted in 2,225 hectares dedicated to local cheese production and 20,784 hectares dedicated to local beef production, which used all of the local land. The rest of the food was imported. We can see that if no waste is produced, only 51% of urban land is required, and in the case of rural land, a no-waste assumption makes room for local dairy production, perhaps due to the high waste prevalence with dairy. In this scenario we only achieve a10% emission reduction, and even in the assumption of zero waste, we only achieve a 42% reduction. This is important. It strongly suggests that what we grow may matter more than how we grow it.

Table 5 Recommended Diet Results for Omnivore Diet

Food Category	Land Allocation with Waste	GHG emissions with Waste (Metric tons)	Land Allocation with no waste	GHG emissions with no waste
Grown in Urban Areas				
Fruit	1597	0	455	0
Vegetables	1748	0	909	0
Grown in Rural Areas				
Grains	278	444	2,453	3,921
Beef	23,760	65,072	19,467	19,466
Pork	0	0	0	0
Dairy (Milk)	101	1,123	2,297	25,634
Soybean	555	5,663	278	2832
Chicken	861	990	784	2,336
Imported				
Eggs	2,974 (N/A)	3,423	1,784	2,054
Chicken	9407 (N/A)	15,972	7,225 (N/A)	12,267
Pork	10,004	15,221	7,202 (N/A)	10,958
Beef	3,277	13,006	0	0
Dairy	3,276	56,268	0	0
Grown in Riparian Areas				
Nuts and Seeds	467	0	236	0
Total		180,372		79,468

Note. For the omnivore diet, the difference between waste is critical given land constraints.

By shifting to a recommended diet, our model suggests that large changes occur. In this case, all vegetables and fruit can be grown in urban areas and local while still, eggs, chicken, pork and beef all require imports. This means that vegetables and fruits are grown with no emissions, and all local food is grown in an agro-ecological manner. This recommended diet, and local production yield a 39% reduction in emissions from the baseline.

Table 6 Recommended Diet Results for Vegan with Dairy

Food Category	Land Allocation with Waste	GHG emissions with Waste (Metric tons)	Land Allocation with no waste	GHG emissions with no waste
Grown in Urban Environments				
Fruits	2,810	0	1124	0
Beans and Peas	266	0	1291	0
Vegetables	269	0	268	0
Grown in Rural Environments				
Fruits	0	0	0	0
Vegetables	3,319	0	0	0
Grains	4,231	4668	1,986	2,879
Soybean (for oil)	364	3,711	182	1,855
Dairy?	6,851	51,987	4,658	47,165
Grown in Riparian areas				
Nuts and Seeds	1,378	0	689	0
Total		17,685+ (*76,464)		8,393 +(*51,987)

This diet and production combination yields the greatest reduction in emissions. Fruits, beans and peas are grown in urban areas, while fruits, vegetables, grains, soybeans and dairy, nuts and seeds, are all grown locally. By increasing the intensity of food production and avoiding extensive production such as meat and poultry, all food grown takes advantage of the climate-friendly agriculture, and

Chittenden County, could potentially become food secure by growing within its own borders. In this scenario we see a 94% reduction in emissions.

4.4.3. Result Summary:

Table 7 Result Summary

Consumption Pattern	GHG emissions with Consumption Waste (Metric Tons)	Per Person Per Day-with waste (kg, ghg emissions)	GHG emissions without Consumption Waste (Metric Tons)	Per Person Per day-without waste
National Baseline Without Processing Estimate	292,000	5	204,400	3.5
Locally Grown Baseline	209,003		137,652	2.3
Recommended Diets				
Omnivore	180,372	3.1	79,468	1.23
Vegan (Dairy)	17,685+ (76,464)	.27+(1.2)	8,393 +(51,987)	.13+(.8)

Note. Dairy is vegan with milk.

In summary, our baseline is roughly 292,000 metric tons per year (MTPY), which can be improved to 209,003 MTPY by growing some food locally, and 180,372 MTPY by eating the recommended diet and engaging with urban agriculture and local climate-friendly production; and finally to 17,685 MTPY, by eating the recommended vegan diet and growing all food locally with climate-friendly production.

4.5. Discussion

This analysis demonstrates that food system mitigation consistent with the (IPCC, 2014) call for 80% reduction in emissions by 2050 in Chittenden County, Vermont is not biophysically impossible or technologically impossible. Instead, it is institutionally, culturally, and socially challenging. However, modern science is discovering that human cooperation exceeds the scale and variety of cooperative activities in comparison with all other species on earth (Melis & Semmann, 2010).

Our findings point to the multiplicative mitigation power of urban gardening, which reduce the opportunities emissions in distribution, waste, processing and storage throughout the supply chain, and also spare land for local food production while enhancing health. Approximately one in two Americans currently suffer from preventable, yet chronic diseases, often related to diet and inactivity. This comes at enormous costs. For instance, in 2012, diagnosed diabetes cost an estimated 245$ billion in the United States. ((CDC), 2015).

At the foodshed scale we can explore feedbacks. Unlike previous authors such as Heller & Keoleian (2014) we find that switching from the conventional American diet to the recommended diet, may cut emissions by more than a third when considering geographical and social context. Similarly, many analyses find that local food production is not helpful for mitigation. However, the possibility of a concerted focus on farm production and food distribution can change these dynamics entirely. The interaction between land constraints, diet, and GHG emissions are also likely to be amplified at larger scales, and also amplified in more rigorous analysis, when we consider that land intensive production is likely to promote the use of marginal lands which require greater inputs and further exacerbate ecological constraints.

It is important to remember that in the face of climate instability, researchers recommend that production be diversified with polycultures, agroforestry systems, and crop-livestock systems and management of soil organic matter and seed selection. (M.

A. Altieri, Nicholls, Henao, & Lana, 2015; M. Altieri & Nicholls, 2004). This needs to be explored further.

There is uncertainty in this analysis regarding emission estimates, sequestration potential, and also yields. Determining what can be grown where, in what quantities, and over what time periods is non-trivial. Reality may be either favorable or unfavorable in comparison with our estimates; though we have been intentionally conservative. Similarly, the winter months, and unpredictable weather may cause unforeseen challenges. If research is continued in the foodshed, it would be advisable to take further steps in understanding sequestration potential, optimal land, and optimal plant varieties for health and GHG reduction.

It is unclear how well these results translate to other regions and towns. Burlington, Vermont is a northern city, and the most densely populated in Vermont; though it is far less populated than other regions. Also, it is unclear how much urban land area can contribute to loosening global land constraints. Currently, lawns are the number one crop grown in the United States and thus provide immense potential (Milesia et al., N.D.) And the ratio of available lawn space to crop area is greater nationally than locally. In this sense, these results are very relevant.

Even with an agro-ecological vision, there is an unexplored tension regarding the recycling of waste from livestock and humans. Without synthetic fertilizers, plants which sequester nitrogen, and manure become increasingly important. There are many cities which already recycle human waste, as biosolids; but this requires infrastructural and regulatory adaptation (eg. City and County of San Fransisco 2009). In future research, we will be looking at the potential for local farms to utilize human waste.

The mitigation potential we explore in this paper is seemingly radical, but it may be an appropriate time for western civilization to move toward the prioritization of health and environment, over increased economic throughput. If this shift is not proactive, it is likely to be reactive, (Homer-Dixon et al., 2015). In the short term, however, this shift is about an ethical understanding of our relationship with the supply chain, and the lives of humans and non-human species around the world; as well as our role in shaping the ecosystem which future generations inhabit. Bringing production closer to home, helps to internalize what are otherwise externalities regarding the impact of our food choices on environment, people and animals.

4.6. Conclusion

There have been many approaches to climate change mitigation in the food system. For farmers and researchers, this includes increasing yields, decreasing inputs, building soil which retains nutrients, sequestering carbon, increasing biomass. For retail and consumers, this means reducing food miles, eating less and eating less GHG intensive foods, eating seasonally, being aware and knowledgeable about emissions in production, transport and storage, adopting new standards of quality, and for variability of supply, and incentivizing management which builds soils (Garnett, 2008). Agents involved in the distribution can also take steps to increase the efficiency of process and transport. All parties involved can decrease waste. In order to mitigate climate change in accordance with IPCC (IPCC, 2014) recommendations, we have to work toward solutions which take this network of actions into account. This is because, consumer, producer, processor, or distributor alone, have the power to mitigate emissions sufficiently, (Owen, Seaman, & Prince, 2007; P. White et al., 2009) and in many cases, mitigation strategies constrain or enhance parallel mitigation strategies. While much research focuses on narrow measurement of the farm scale, efficiency is largely context dependent.

It is difficult to take multiple considerations into account at larger scales though this is also important. For instance, Peters et al. (2016) focus on the entire United States looking at carrying capacity. When we zoom in however, we consider a variety of production methods and land types ranging from lawn gardens to large scale monocrop production, and find emergent synergies and challenges. In this research, we find that land availability interacts dramatically with crop type when considering GHG emissions. For instance, producing for land extensive diet requirements, allows for land intensive, climate friendly production, such as perennial production which has immense carbon sequestering capacity. Such perennial production is rarely associated with land extensive diets but with intentional planning it can be.

The most important finding from our research is that urban fruit and vegetable production and consumption can make important contributions to climate change mitigation. Through urban production, emissions which would occur in earlier stages of the supply chain such as transportation, and retail are skipped, along with the waste that occurs in these stages. Further, per unit of land fruit and vegetables contribute more significantly to satisfying a recommended diet. This allows for more food production within the region. If land was not a scarce resource this would not make a difference. However, in this context, with real constraints, this leads to mitigation potential because a greater quantity of necessary production can occur in a manner which does not depend on the conventional supply chain. We may also see a long term benefit of increased fruit and vegetable consumption. This is because efficiency is determined not only within the food supply chain, but also within the human digestive system. Enhancing the body's capacity to discern requirements, break down foods and determine satiation will decrease food cravings and overeating (Sonnenburg et al. 2016, Mayer 2011). This occurs because this food source is rich in fiber and phytochemicals, and is less processed, and flavored than foods which are grown at far distances. Thus, this effort not only is more efficient per calorie; it is also likely to reduce the total number of calories required for satiation and health. As we gain more information about the impact of diet in utero and in early childhood, it seems that a leverage point in mitigation, would be to make local produce very accessible at these stages in life. In the long run, this is likely to build the capacity to meet food cravings with the diverse nutrient range which low-GHG intensive foods provide.

There is cultural precedence for this type of large scale urban gardening. In effort to reduce pressure on various resources, such as transportation, gardens were planted over lawns and in public parks during World Wars I and II in the U.S., the U.K., Canada, Australia and Germany. Various local and national agencies played a role in this. These efforts were often launched through 'campaigns' such as the "Dig on for Victory" campaign in Australia, Canada's "A Vegetable Garden for Every Home" and the United States "Victory Gardens". Projects were often implemented through a mix of volunteer organizations, education systems and military funding. In 1943, the United States was home to 18 million victory gardens, producing as much as all commercial production in fresh vegetables.

Humanity is facing the potential for an emerging crisis at the intersection of mounting constraints related to food and the environment. These crises already persist in many regions of the world today; and maintaining boundaries across resources and populations, is often achieved at the further expense of peace and stability. The United States Department of Defense and NATO, both consider climate change as threat multipliers. Climate change among other slow building constraints are expected to deeply exacerbate refugee problems and disrupt political stability (DOD, 2015). We can also expect that governments may be increasingly repressive as problems provide less flexible solution spaces.

Today, the majority of humanitarian aid is going to regions with persistent need lasting more than eight years. There is a need to develop systemic solutions for food system sustainability and resilience.

In addition to broad global benefits, urban gardening can have a variety of benefits across economic, social and physiological domains. Urban gardens have been shown to dramatically decrease crime (Kuo and Sullivan, 2001), and cultivate interaction within neighborhoods. They provide nutrient rich food in what are often food deserts, and are associated with increased fruit and vegetable consumption in addition to reducing exposure to pesticides and preservatives (Bremer et al., 2003). Gardens are also shown to help people recover from mental fatigue, and stress while improving satisfaction and provide myriad physiological benefits (Maller et al., 2005).

In conclusion, it stands that urban fruit and vegetable production should be supported, and perhaps heavily subsidized, for climate change mitigation, community building and for health reasons. Also, agronomic efficiency research is enhanced by capturing complexity at the level of the foodshed.

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CHAPTER 5. CONCLUSION

The esoteric contemplations in second-order cybernetics provide cohesion for systems theory, and can be useful in understanding the emergence of manageable social-ecological systems. The connected notions of feedback, circularity, dynamic equilibriums, self-organization, and emergence can all be understood as ‘outward’ expressions or ‘inward’ expressions. Navigating this distinction is instrumental in the pursuit of foundations for any structured inquiry.

To explore this distinction briefly, we can imagine a structure emerging in a set of cross-cutting waves, we may consider this to be a dynamic system, that we can point to ‘out there’. Intrinsic to these dynamic systems is ‘feedback’, and the reproduction of balance. Reflecting on ourselves we notice our distinction between waves and the surface across which they move. Imagine that we define waves as changes to the surface of the sea, and the surface of the sea, as constituted by the balance of waves. This balance is ‘imaginary’. A wave ultimately changes the balance against which it is perceived. In this ‘inward’ or ‘second-order’ case of circularity, we find that our distinctions change the balance against which they are measured; and so, their existence is ultimately self-referential. Second-order theory elucidates this relationship between reflexivity and observation as to cast the notion of ‘self-organizing systems’ in a new light. Perhaps the magical revelation of second-order cybernetics is that circularity is not only the root of paradox and often contradiction, it is also the creative force that creates the space for any inquiry. It opens up a cognitive domain (Varela, 1984). Transferring transdisciplinary concepts to alternative domains is difficult, and this may be part of the reason that circularity and second-order cybernetics are often misunderstood.

Ecological Economics offers a nice opportunity for considering the construction of a perspective. Ecological Economics might be relatable to other action oriented sciences, and social-ecological conceptualizations of organizational closure.

The field aims to integrate two cognitive domains so this exploration should also serve as an example of integrating disciplines, and in particular, integrating social systems and the ecosystem.

This circularity occurs when we define scale according to prices, (Daly & Farley, 2011; Vatn & Bromley, 1997) and when we use deliberative methods (Malghan, 2010) for determination of scale and related approaches to just resource distribution. (Figge, Hahn, & Barkemeyer, 2014; Young, 2000). In each case, the difference that the other system makes, changes the balance against which that difference was initially defined. This circularity is perceived as prohibitive, instead of as a natural occurrence.

In one such formalization Malghan (2010) finds that *"At any given point in time, only one of the equations [optimal scale] or [distribution] can be valid."* This sentiment reminds us of conclusions drawn based on "Laws of Form", (Spencer-Brown, 1969). As Kauffman, (2011) recalls, *"[What] may appear contradictory in a space may appear without paradox in space and time."* In this self-referential engagement we remember von Foerster's (1973) ethical imperative, *"Act always so as to increase the number of choices."*

Second-order cybernetics represents a paradigm shift in the understanding of understanding. As opposed to objectivity emerging from the negation of subjectivity, the opposite becomes true. By applying the logic of recursion, or the rules of the 'object' back onto the selectivity of the subject, 'reality' seems to emerge.

In the words of Francisco Varela (1983)*"[reality or common] ground is a very feminine quality of making something possible, as opposed to a very masculine quality of 'the out there', that you have to fit into."* For highly intelligent systems thinkers, the beginning of the world is absolutely complex, and thus, indescribable. From this perspective, we work up to ‘second order complexity’ as a control strategy. However, there is another experience, such as Spencer Brown’s (1969), who writes, “Draw a distinction”. From this alternative starting point, reality is absolutely simple, and thus indescribable. From this point, we work up to ‘first order reality’, with oscillating relationships.

In addition to the jockeying of ecologists and economists, in the pursuit for theoretical foundations we find many attempts to ‘step outside’, to sever the space between the regulated and the regulator. We see this on the project scale for instance in the necessity to develop ‘second-order conditions’ from “behind the veil” (e.g. Malghan, (2010) citing Rawls, (2005)). Following the scientific tradition, there are calls within the field for developing an ontology, epistemology and methodology (Spash, 2012). Daly and Farley (2011) suggest that ultimate ends and ultimate means inform the basis for political economy. Though they may not be seen this way, such ‘foundations’ are, according to second-order cybernetics, ‘a choice’(Heinz von Foerster, 1973), separating the chooser, from the chosen. Participation is only obvious when the perceived inputs and the boundaries between them (these foundations) are modified by the process of Ecological Economics itself. Whichever path we choose, we seem to eventually be subject to the constraints which we create. For instance, the aims which prompt the distinction of the food system, may be changed by the demands for the maintenance of this distinction.

As we consider the food system within the ecological economy, we treat it in two manners, dualistically. On the one hand, we treat it as a symbol for coordinated activity, and on the other a black box which produces an output. Together, it is a symbol suggesting that ‘if one acts in this way, this information will be derived in order to guide further action.’ In other words, the food system becomes a necessary coordination of activity when it comes to establishing the boundary between the ecosystem and the economy.

In order to achieve adequate climate change mitigation in the food system, the food system as we know it would need to go through an immense phase of decentralization. This is because current control systems cannot react on the scales necessary to be sensitive to relevant changes in the environment for ecological integrity and human health. Accompanying this, agricultural science, should be sensitive to an expanded set of viable ways of producing and consuming food. As we imagine a new food system and coordination among distributed actors, it is our challenge to design institutions which enable the appropriate communicate channels. The foodshed may be a scale at which otherwise incongruent political, ecological, technological, economic and social aims may be applied in concert. The market fails to achieve optimality in the case of essential, non-substitutable, non-renewable, non-rival, and non-excludable services provided by people and nature (Daly & Farley, 2011). The food system, is an opportunity to reimagine institutions which are appropriate in the presence of these characteristics.

The possibility of reducing production emissions by 80% while sustaining yields requires an intensive approach to organic, or semi-organic farming. It is only in the context of agro-ecological production that local food enhances our mitigation potential; and it is likely that the social capital which emerges in the context of local production, provides the possibility for supporting farmers in realizing this vision. By developing a tighter coupling between consumer and citizen decisions, and social-environmental impacts, it is more likely that novel forms of self-regulation will emerge. Another feedback occurs in the relationship between producers, researchers and regulators, (Méndez, Bacon, & Cohen, 2013) and emergence can be fostered in the case of transdisciplinary, and participatory action research. This is important in the face of the complexity of the agro-ecosystem and is impacted by policies. For instance, (Vatn, 2009) finds that payments for ecosystem services have the capacity to produce novel social organizations for the reduction of transaction costs. In fact, some payment approaches can build cooperative efforts into the fabric of incentive structures. Schmitt et al. (2013) find a way to integrate agro-ecology, participatory action research and payments for ecosystem services. These dynamic structures, facilitate the necessary emergence and adaptation in the face of agro-social-ecological complexity. Lastly, intrinsic motivation may be enabled when people are empowered and aware of impacts. For instance, (Erickson, Lovell, & Méndez, 2011) find that within the region many land owners would be willing to share their land for agricultural production. Again, all of this is only possible when a variety of institutions are able to act in concert over a particular scale.

We have found in this paper that achieving substantial mitigation is viable with the use of urban agriculture, and agro-ecology. These activities are appropriately coordinated at the foodshed scale, and thus the ‘foodshed’ should become a prominent entity within the subdomains of Ecological Economics.

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