Chapter 16
Aquaponics for the Anthropocene: Towards a 'Sustainability First' Agenda

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Abstract 'The Anthropocene' has emerged as a unique moment in earth history where humanity recognises its devastating capacity to destabilise the planetary processes upon which it depends. Modern agriculture plays a central role in this problematic. Food production innovations are needed that exceed traditional paradigms of the Green Revolution whilst at the same time are able to acknowledge the complexity arising from the sustainability and food security issues that mark our times. Aquaponics is one technological innovation that promises to contribute much towards these imperatives. But this emergent field is in an early stage that is characterised by limited resources, market uncertainty, institutional resistance and high risks of failure—a developmental environment where hype prevails over demonstrated outcomes. Given this situation, the aquaponics research community potentially holds an important place in the development path of this technology. But the field needs to craft a coherent and viable vision for this technology that can move beyond misplaced techno-optimist accounts. Turning to sustainability science and STS research, we discuss the urgent need to develop what we call a 'critical sustainability knowledge' for aquaponics, giving pointers for possible ways forward, which include (1) expanding aquaponic research into an interdisciplinary research domain, (2) opening research up to participatory approaches in real-world contexts and (3) pursuing a solution-oriented approach for sustainability and food security outcomes.

Keywords Anthropocene · Green Revolution · Techno-optimism · STS research (Science, Technology and Society research)

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S. Goddek et al. (eds.), *Aquaponics Food Production Systems*,
https://doi.org/10.1007/978-3-030-15943-6_16

16.1 Introduction

Key drivers stated for aquaponic research are the global environmental, social and economic challenges identified by supranational authorities like the Food and Agriculture Organization (FAO) of the United Nations (UN) (DESA 2015) whose calls for sustainable and stable food production advance the 'need for new and improved solutions for food production and consumption' (1) (Junge et al. 2017; Konig et al. 2016). There is growing recognition that current agricultural modes of production cause wasteful overconsumption of environmental resources, rely on increasingly scarce and expensive fossil fuel, exacerbate environmental contamination and ultimately contribute to climate change (Pearson 2007). In our time of 'peak-everything' (Cohen 2012), 'business as usual' for our food system appears at odds with a sustainable and just future of food provision (Fischer et al. 2007). A food system revolution is urgently needed (Kiers et al. 2008; Foley et al. 2011), and as the opening chapters (Chaps. 1 and 2) of this book attest, aquaponics technology shows much promise. The enclosed systems of aquaponics offer an especially alluring convergence of potential resolutions that could contribute towards a more sustainable future (Kőmíves and Ranka 2015). But, we ask, what kind of sustainable future might aquaponics research and aquaponics technology contribute towards? In this chapter, we take a step back to consider the ambitions of our research and the functions of our technology.

In this chapter we situate current aquaponic research within the larger-scale shifts of outlook occurring across the sciences and beyond due to the problematic that has become known as 'the Anthropocene' (Crutzen and Stoermer 2000b). Expanding well beyond the confines of its original geological formulation (Lorimer 2017), the Anthropocene concept has become no less than 'the master narrative of our times' (Hamilton et al. 2015). It represents an urgent realisation that demands deep questions be asked about the way society organises and relates to the world, including the *modus operandi* of our research (Castree 2015). However, until now, the concept has been largely sidelined in aquaponic literature. This chapter introduces the Anthropocene as an obligatory frame of reference that must be acknowledged for any concerted effort towards future food security and sustainability.

We discuss how the Anthropocene unsettles some key tenets that have underpinned the traditional agriscience of the Green Revolution (Stengers 2018) and how this brings challenges and opportunities for aquaponic research. Aquaponics is an innovation that promises to contribute much towards the imperatives of sustainability and food security. But this emergent field is in an early stage that is characterised by limited resources, market uncertainty, institutional resistance with high risks of failure and few success stories—an innovation environment where hype prevails over demonstrated outcomes (König et al. 2018). We suggest this situation is characterised by a misplaced techno-optimism that is unconducive to the deeper shifts towards sustainability that are needed of our food system.

Given this, we feel the aquaponics research community has an important role to play in the future development of this technology. We suggest a refocusing of aquaponics research around the key demands of our food system—sustainability and food security. Such a task entails we more thoroughly consider the nature of sustainability, and so we draw on the insights from the fields of sustainability science and STS. Addressing sustainability in the Anthropocene obligates the need to attend more holistically the interacting biophysical, social, economic, legal and ethical dimensions that encroach on aquaponic systems (Geels 2011). This is no small task that places great demands on the way we produce and use knowledge. For this reason we discuss the need to develop what we call a ‘critical sustainability knowledge’ for aquaponics, giving pointers for possible ways forward, which include (1) expanding aquaponic research into an interdisciplinary research domain, (2) opening research up to participatory approaches in real-world contexts and (3) pursuing a solution-oriented approach for sustainability and food security outcomes.

16.2 The Anthropocene and Agriscience

‘Today, humankind has begun to match and even exceed some of the great forces of nature [...] [T]he Earth System is now in a no analogue situation, best referred to as a new era in the geological history, the Anthropocene’ (Oldfield et al. 2004: 81).

The scientific proposal that the Earth has entered a new epoch—‘the Anthropocene’—as a result of human activities was put forward at the turn of the new millennium by the chemist and Nobel Laureate Paul Crutzen and biologist Eugene Stoermer (Crutzen and Stoermer 2000a). Increasing quantitative evidence suggests that anthropogenic material flows stemming from fossil fuel combustion, agricultural production and mineral extraction now rival in scale those natural flows supposedly occurring outside of human activity (Steffen et al. 2015a). This is a moment marked by unprecedented and unpredictable climatic, environmental and ecological events (Williams and Jackson 2007). The benign era of the Holocene has passed, so the proposal claims; we have now entered a much more unpredictable and dangerous time where humanity recognises its devastating capacity to destabilise planetary processes upon which it depends (Rockström et al. 2009, Steffen et al. 2015b; See chapter 1). The Anthropocene is therefore a moment of realisation, where the extent of human activities must be reconciled within the boundaries of biophysical processes that define the safe operating space of a stable and resilient Earth system (Steffen et al. 2015b).

A profound intertwining of the fates of nature and humankind has emerged (Zalasiewicz et al. 2010). The growing awareness of environmental and human calamity—and our belated, tangled role within it—puts to test our faith in the key modernist assumption, namely, the dualisms separating humans from nature (Hamilton et al. 2015). This is a shocking and unprecedented moment because modernist epistemologies have proven exceedingly powerful, contributing significantly towards the organisation of society to the present day (Latour 1993). Conceptions of unique and stable human agency, the presumption of progressive norms such as liberty or universal dignity, and the existence of an objective world separate from human doings are all put to test (Latour 2015; Hamilton et al. 2015).

This insight, without doubt, applies to the food system of which we all inherit. The Green Revolution[1] was underpinned with modern aspirations, being founded on ideas such as linear notions of progress, the power of human reason and faith in the inevitable technological resolution of human problems (Cota 2011). These conceptions, which have traditionally secured the role of science in society, begin to appear increasingly unreliable with the advent of the Anthropocene (Savransky 2013; Stengers 2015). The inconvenient truth is that the technoscientific interventions, which have been implemented as modern agrarian solutions onto our world over the last century, have carried with them serious and unexpected outcomes. What's more, these escalating biophysical disruptions (e.g. greenhouse gas emissions and nitrogen and phosphorous cycle perturbations) that have only recently become perceived must be added to a much broader series of environmental, biological and social repercussions brought about by particular aspects of our modernised food system.

The Anthropocene problematic leaves little doubt that our contemporary food system faces enormous challenges (Kiers et al. 2008; Baulcombe et al. 2009; Pelletier and Tyedmers 2010). Prominent studies point to agriculture as the single largest contributor to the rising environmental risks posed in the Anthropocene (Struik and Kuyper 2014; Foley et al. 2011). Agriculture is the single largest user of freshwater in the world (Postel 2003); the world's largest contributor to altering the global nitrogen and phosphorus cycles and a significant source (19–29%) of greenhouse gas emissions (Vermeulen et al. 2012; Noordwijk 2014). Put simply, 'agriculture is a primary driver of global change' (Rockström et al. 2017:6). And yet, it is from within the new epoch of the Anthropocene that the challenge of feeding humanity must be resolved. The number of hungry people in the world persists at approximately 900 million (FAO, Ifad and WFP. 2013). Even then, in order to feed the world by 2050, best estimates suggest that production must roughly double to keep pace with projected demands from population growth, dietary changes (particularly meat consumption) and increasing bioenergy use (Kiers et al. 2008; Baulcombe et al. 2009; Pelletier and Tyedmers 2010; Kearney 2010). Complicating matters even further is the need not simply to produce more, but also to manage the entire food system more efficiently. In a world where 2 billion suffer from micronutrient deficiencies, whilst 1.4 billion adults are over-nourished, the need for better distribution, access and nutrition is glaring, as is the drastic need to reduce the deplorable levels of waste (conservative estimates suggest 30%) in the farm-to-fork supply chain (Parfitt et al. 2010; Lundqvist et al. 2008; Stuart 2009).

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[1] The Green Revolution refers to a set of research and technology transfer initiatives occurring from the 1930s and the late 1960s that increased agricultural production worldwide, particularly in the developing world. As Farmer (1986) describes, these initiatives resulted in the adoption of new technologies, including: 'New, high-yielding varieties of cereals... in association with chemical fertilizers and agro-chemicals, and with controlled water-supply... and new methods of cultivation, including mechanization. All of these together were seen as a "package of practices" to supersede "traditional" technology and to be adopted as a whole'.

The Anthropocene problematic presents serious questions about modern industrial agriculture, which in many guises is now deemed inefficient, destructive and inadequate for our new global situation. But the fallout of this situation is more considerable still, for the Anthropocene strikes a challenge at the very agricultural paradigm currently dominating food provision (Rockström et al. 2017). For this reason the challenge extends well beyond 'the farm' and incorporates a much wider set of structures, practices and beliefs that continue to enact and propel the modern agricultural paradigm into our newly demanding epoch. With this comes the urgent need to reconsider the methods and practices, ambitions and goals that define our current agriscience research. Are they fit for the challenges of our new epoch, or do they merely reproduce inadequate visions of modernist food provision?

16.3 Getting Beyond the Green Revolution

The Anthropocene marks a step change in the relation between humans and our planet. It demands a rethink of the current modes of production that currently propel us on unsustainable trajectories. Until now, such reflexive commitments have not been required of agriscience research and development. It is worth remembering that the Green Revolution, in both its ambitions and methods, was for some time uncontroversial; agriculture was to be intensified and productivity per unit of land or labour increased (Struik 2006). Without doubt, this project, whose technological innovations were vigorously promoted by governments, companies and foundations around the world (Evenson and Gollin 2003), was phenomenally successful across vast scales. More calories produced with less average labour time in the commodity system was the equation that allowed the cheapest food in world history to be produced (Moore 2015). In order to simplify, standardise and mechanise agriculture towards increases in productivity per worker, plant and animal, a series of biophysical barriers had to be overridden. The Green Revolution achieved this largely through non-renewable inputs.

In the Anthropocene, this agricultural paradigm that marked the Green Revolution runs up against (geological) history. Growing awareness is that this 'artificialised' agricultural model, which substitutes each time more ecological processes with finite chemical inputs, irrigation and fossil fuel (Caron et al. 2014), literally undermines the foundations of future food provision. The biophysical contradictions of late-capitalist industrial agriculture have become increasingly conspicuous (Weis 2010). Moreover, the dramatic environmental, economic and social consequences of contemporary models of high-intensity artificialised agriculture have become an escalating concern for a globalised food system manifesting accelerating contradictions (Kearney 2010; Parfitt et al. 2010).

During the post-war period (mid-40s–70s), secure economic growth was founded on the accelerated extraction of fossil fuel, and as Cota (Cota 2011) notes, agriscience development during this time progressed more in tune with the geochemical sciences than the life sciences. Agricultural production designed around the cheapest maximum yields had been simplified and unified into monocrops, made to depend on mechanisation and agrochemical products. Although highly effective when first implemented, the efficiency of these commercial inputs has witnessed diminishing returns (Moore 2015). Following the oil crises of the 70s, the productivist ideals of the Green Revolution fell more upon the life sciences, particularly in the guise of agri-biotech, which has grown into a multibillion-dollar industry.

Feeding the globe's exploding population has been the key concern in a decade-long productivist narrative that has served to secure the prominent position of agricultural biotech in our current food system (Hunter et al. 2017). The great shock is that this highly advanced sector has done little to improve intrinsic yields. World agricultural productivity growth slowed from 3% a year in the 1960s to 1.1% in the 1990s (Dobbs et al. 2011). Recently, the yields of key crops have in some places approached plateaux in production (Grassini et al. 2013). Mainstream agroscientists have voiced concern that the maximum yield potential of current varieties is fast approaching (Gurian-Sherman 2009). On top of this, climate change is estimated to have already reduced global yields of maize and wheat by 3.8% and 5.5%, respectively (Lobell et al. 2011), and some warn of sharp declines in crop productivity when temperatures exceed critical physiological thresholds (Battisti and Naylor 2009).

The waning efficiency gains of artificial inputs added to the biological limits of traditional varieties is a situation that, for some, further underscores the need to accelerate the development of genetically engineered varieties (Prado et al. 2014). Even then, the greatest proponents of GM—the biotech firms themselves—are aware that GM interventions rarely work to increase yield, but rather to *maintain* it through pesticide and herbicide resistance (Gurian-Sherman 2009). As such, agricultural production has become locked into a cycle that requires the constant replacement of new crop varieties and product packages to overcome the growing negative environmental and biological impingements upon yield [2]. Melinda Cooper's (2008: 19) influential analysis of agro-biotechnology has traced how neoliberal modes of production become relocated ever more within the genetic, molecular and cellular levels. As such, the commercialisation of agrarian systems increasingly extends towards the capture of germplasm and DNA, towards 'life itself' (Rose 2009). Cooper's (2008) diagnosis is that we are living in an era of capitalist delirium characterised by its attempt to overcome biophysical limits of our earth through the speculative biotechnological reinvention of the future. In this respect, some have argued that rather than overcoming weaknesses of the conventional paradigm, the narrow focus of GM interventions seems only to intensify its central characteristics (Altieri 2007).

Amidst the deceleration of yield increases, the estimated targets of 60–100% increases in production needed by 2050 (Tilman et al. 2011; Alexandratos and Bruinsma 2012) appear increasingly daunting. As compelling and clear as these targets may be, concerns have been raised that productivist narratives have eclipsed other pressing concerns, namely, the environmental sustainability of production (Hunter et al. 2017) and food security (Lawrence et al. 2013). The current agricultural paradigm has held production first and sustainability as a secondary task of mitigation (Struik et al. 2014).

Thirty years of frustrated sustainability talk within the productivist paradigm are testament to the severe difficulties for researchers and policymakers alike to bridge the gap between sustainability theory and practice (Krueger and Gibbs 2007). 'Sustainability' as a concept had initially had revolutionary potential. Key texts such as the Club of Rome's *The Limits of Growth* (Meadows et al. 1972), for instance, contained an imminent critique of global development narratives. But researchers have pointed out the way that 'sustainability' throughout the 80s and 90s became assimilated into neoliberal growth discourse (Keil 2007). We now have a situation where, on the one hand, global sustainability is almost unanimously understood as a prerequisite to attain human development across all scales—from local, to city, nation and the world (Folke et al. 2005)—whilst on the other, despite substantial efforts in many levels of society towards the creation of a sustainable future, key global-scale indicators show that humanity is actually moving away from sustainability rather than towards it (Fischer et al. 2007). This is in spite of the increasing regularity of high-profile reports that evermore underscore the grave risks of existing trends to the long-term viability of ecological, social and economic systems (Steffen et al. 2006; Stocker 2014; Assessment 2003; Stern 2008). This situation—the widening gap between our current trajectory and all meaningful sustainability targets—has been discussed as the so-called 'paradox of sustainability' (Krueger and Gibbs 2007). Prevailing discourse on food security and sustainability continues to galvanise growth-oriented developmental imperatives (Hunter et al. 2017).

Agriscience research and development proliferated in accordance with the dominant politico-economic structures that defined planetary development over the last 30 years (Marzec 2014). Although the negative effects of the so-called 'Chicago School' of development have by now been well documented (Harvey 2007), biotechnological innovation remains rooted within neoliberal discourse (Cooper 2008). These narratives consistently present global markets, biotech innovation and multinational corporate initiatives as the structural preconditions for food security and sustainability. The empirical credibility of such claims has long been challenged (Sen 2001), but seem especially relevant amidst the accumulating history of chronic distributional failures and food crises that mark our times. It is worth repeating Nally's (2011; 49) point: 'The spectre of hunger in a world of plenty seems set to continue into the 21st century. . . this is not the failure of the modern food regime, but the logical expression of its central paradoxes'. The situation is one where malnutrition is seen no longer as a failure of an otherwise efficiently functioning system, but rather as an endemic feature within the systemic production of scarcity (Nally 2011). In the face of such persisting inconsistencies, commentators note that neoliberal appeals to human prosperity, food security and green growth appear out of touch and often ideologically driven (Krueger and Gibbs 2007).

The Anthropocene is a time where ecological, economic and social disaster walk hand in hand as modern economies and institutions geared towards unlimited growth crash against the finite biophysical systems of the earth (Altvater et al. 2016; Moore

2015). Cohen (2013) describes the Anthropocene as an ‘eco-eco’ disaster, paying heed to the rotten relationship in which eco*nomic* debt becomes compounded against the eco*logical* debt of species extinction. Now more than ever, faith in the modernising powers of neoliberal food interventions proclaiming just and sustainable futures wears thin (Stengers 2018), yet the resemblance noted by some commentators (Gibson-Graham 2014), between our food system and the unhinged financial systems of our neoliberal economies charts an alarming trend. It’s worth noting this resemblance runs deeper than the mere production of debt (one being calorific and genetic, the other economic). The truth is our food system hinges on a cash nexus that links trade tariffs, agricultural subsidies, enforcement of intellectual property rights and the privatisation of public provisioning systems. Viewed from above, these procedures constitute a pseudo-corporate management of the food system, which according to Nally (2011: 37) should be seen as a properly *biopolitical* process designed for managing life, “including the lives of the hungry poor who are ‘let die’ as commercial interests supplant human needs”. Petrochemicals and micronutrients, it seems, are not the only things being consumed in the Anthropocene; futures are (Collings 2014; Cardinale et al. 2012).

What once might have been considered necessary side effects of the modernising imperative of the Green Revolution, the so-called ‘externalities’ of our current food system, are increasingly exposed as a kind of ‘deceptive efficiency’ bent towards rapid production and profit and very little else (Weis 2010). The disturbing realisation is that the food system we inherit from the Green Revolution creates value only when a great number of costs (physical, biological, human, moral) are allowed to be overlooked (Tegtmeier and Duffy 2004). A growing number of voices remind us that costs of production go beyond the environment into matters such as the exclusion of deprived farmers, the promotion of destructive diets (Pelletier and Tyedmers 2010) and more generally the evacuation of social justice and political stability from matters of food provision (Power 1999). The relation between agrarian technological intervention, food security and sustainability emerges as far wider and complex issue than could be acknowledged by narratives of the Green Revolution.

Situating the contemporary food system within dominant recent historical processes, the above discussion has paid particular attention to destructive links between modern agriculture and the economic logics of late capitalism. It is important, however, to remember that numerous commentators have cautioned against oversimplified or deterministic accounts regarding the relationship between capitalist relations of production and the Anthropocene problematic (Stengers 2015; Haraway 2015; Altvater et al. 2016). Such a discussion is made possible by close to four decades of critical investigations by feminists, science and technology scholars, historians, geographers, anthropologists and activists, which have endeavoured in tracing the links between hegemonic forms of science and the social/environmental destruction caused by industrial capitalism (Kloppenburg 1991). This ‘deconstructive’ research ethic developed important understandings of the way modern agriscience progressed down trajectories that involve the neglect of particular physical, biological, political and social contexts and histories (Kloppenburg 1991). In many instances, the modernising narratives of 'development' like those put to work in the Green Revolution became seen—by anthropologists, historians and indigenous communities alike—as a kind of modified successor to pre-war colonial discourse (Scott 2008; Martinez-Torres and Rosset 2010). In anthropological terms, what these studies taught us was that although modern agriculture was rooted in developmental narratives of universal prosperity, in reality, 'progress' was achieved through the displacement or indeed destruction of a great diversity of agricultural perspectives, practices, ecologies and landscapes. It is for this reason Cota (2011: 6) reminds us of the importance of the critical work that explicitly positioned the biopolitical paradigm of industrial agriculture 'not first and foremost as an economic kind of imperialism, but more profoundly as an epistemic and culturally specific kind of imperialism'.

This is a key point. The Green Revolution was not merely a technical, nor economic intervention, but involved the spread of a more profound reconfiguration of the epistemological registers of food provision itself. It was a process that deeply influenced the way agricultural knowledge was produced, propagated and implemented. As Cota (2011: 6) explains: 'the use of physicalist and probabilistic discourse, a purely instrumental conception of nature and work, the implementation of statistical calculations disconnected from local conditions, [as well as] the reliance on models without recognizing historic specificities' were all ways of enacting the biopolitical agenda of the Green Revolution. This list of commitments describes the fundamentals at the sharp end of the Green Revolution, but as we have seen, such commitments alone have proven insufficient for the task of creating a just and sustainable food system. It becomes apparent that any research agenda fit for the Anthropocene must learn to move beyond the modern food paradigm by forging a different research ethic with different commitments.

16.4 Paradigm Shift for a New Food System

To claim that Agriculture is 'at a crossroads' (Kiers et al. 2008) does not quite do justice to the magnitude of the situation. The gaping 'sustainability gap' (Fischer et al. 2007) amidst unanimous calls for sustainability are increasingly being met with common response amongst researchers: pleas for revolutionary measures and paradigm shifts. Foley et al. (2011: 5) put it quite directly: 'The challenges facing agriculture today are unlike anything we have experienced before, and they require revolutionary approaches to solving food production and sustainability problems. In short, new agricultural systems must deliver more human value, to those who need it most, with the least environmental harm'. Somehow, world agriculture's current role as the single largest driver of global environmental change must shift into a 'critical agent of a world transition' towards global sustainability within the biophysical safe operating space of the Earth (Rockström et al. 2017).

The Anthropocene lays steep demands: Agriculture must be intensified; it must meet the needs of a growing population, but at the same time it is mandatory that the pressures exerted by our food production systems stay within the carrying capacity of Planet Earth. It is increasingly understood that future food security depends on the development of technologies that increase the efficiency of resource use whilst simultaneously preventing the externalisation of costs (Garnett et al. 2013). The search for alternatives to our current agricultural paradigm has brought to the fore ideas such as agroecology (Reynolds et al. 2014) and 'sustainable intensification', with the acknowledgement that real progress must be made towards 'ecological intensification', that is, increasing agricultural output by capitalising on the ecological processes in agroecosystems (Struik and Kuyper 2014).

There has been well-documented debate on what constitutes 'sustainable intensification' (SI) of agriculture as well as the role it might play in addressing global food security (Struik and Kuyper 2014; Kuyper and Struik 2014; Godfray and Garnett 2014). Critics have cautioned against the top-down, global analyses that are often framed in narrow, production-oriented perspectives, calling for a stronger engagement with the wider literature on sustainability, food security and food sovereignty (Loos et al. 2014). Such readings revisit the need for developing regionally grounded, bottom-up approaches, with a growing consensus claiming that an SI agenda fit for the Anthropocene does not entail 'business-as-usual' food production with marginal improvements in sustainability but rather a radical rethinking of food systems not only to reduce environmental impacts but also to enhance animal welfare, human nutrition and support rural/urban economies with sustainable development (Godfray and Garnett 2014).

While traditional 'sustainable intensification' (SI) has been criticised by some as too narrowly focused on production, or even as a contradiction in terms altogether (Petersen and Snapp 2015), others make it clear that the approach must be broadly conceived, with the acknowledgement that there is no single universal pathway to sustainable intensification (Garnett and Godfray 2012). Important here is the growing appreciation of 'multifunctionality' in agriculture (Potter 2004). If, during the twentieth century, 'Malthusian' demographics discourse had secured the narrow goal of agricultural development on increasing production, the growing rediscovery of the multiple dimensions of farming currently taking place is altering the perception of the relationship between agriculture and society.

'Multifunctionality' as an idea was initially contested in the context of the controversial GATT and WTO agricultural and trade policy negotiations (Caron et al. 2008), but has since gained wide acceptance, leading to a more integrative view of our food system (Potter 2004). In this view, progress in seeing agriculture as an important type of 'land use' competing with other land functions (Bringezu et al. 2014) interrelates with a number of other perspectives. These have been conceptualised through several important categories: (1) as a source of employment and livelihood for a rural and future urban population (McMichael 1994); (2) as a key part of cultural heritage and identity (van der Ploeg and Ventura 2014); (3) as the basis of complex value chain interactions in 'food systems' (Perrot et al. 2011); (4) as a sector in regional, national and global economies (Fuglie 2010); (5) as modifier and storehouse of genetic resources (Jackson et al. 2010); (6) as a threat to environmental integrity that exerts destructive pressures on biodiversity (Brussaard et al. 2010; Smil 2011); and (7) as a source of greenhouse gas emissions (Noordwijk

2014). This list is by no means comprehensive, but what is important is that each of these interacting dimensions is understood to impact sustainability and food security in one way or another and must be apprehended by serious attempts towards SI.

Sustainability outcomes are increasingly seen as a complex interplay between local and global concerns (Reynolds et al. 2014). Biophysical, ecological and human needs intermix within the complexities and idiosyncrasies of 'place' (Withers 2009). The 'one size fits all' solutions, characteristics of the Green Revolution, fail to acknowledge these unique sustainability potentials and demands. The result is that changes in food production and consumption must be perceived through a multiplicity of scales *and* styles. To this end, Reynolds et al. (2014) suggest an approach to sustainability that takes advantage of the insights of agroecological principles. They forward a 'custom-fit' food production focus 'explicitly tailored to the environmental and cultural individuality of place and respectful of local resource and waste assimilative limits, thus promoting biological and cultural diversity as well as steady-state economics'.

If the issues at stake are inherently *multidimensional*, others have also underlined that they are *contested*. Trade-offs between the plethora of biophysical and human concerns are inevitable and often exceedingly complex. Sustainability thresholds are diverse, often normative, and can seldom all be realised in full simultaneously (Struik and Kuyper 2014). It has been emphasised that new directions towards sustainability and food security require simultaneous change at the level of formal and informal social rules and incentive systems (i.e. institutions) that orient human interaction and behaviour, and hence that 'institutional innovation' is held to be a key entry point in addressing challenges (Hall et al. 2001). Insomuch as the complexity of sustainable intensification derives from human framings (which entail and flow from contexts, identities, intentions, priorities and even contradictions), they are, as Kuyper and Struik (2014: 72) put it, 'beyond the command of science'. Attempting to reconcile the many dimensions of food production towards sustainable ends and within the bounds of our finite planet involves a great deal of uncertainty, irreducibility and contestation (Funtowicz and Ravetz 1995); it requires an awareness and acknowledgement that such issues are shot through with *political* implication.

Food systems and sustainability research have come a long way in expanding the narrow focus of the Green Revolution, bringing greater clarity to the steep challenges we face in the pursuit of a more environmentally and socially sustainable food system. Thanks to a broad range of work, it is now apparent that food production lies at the heart of a nexus of interconnected and multi-scalar processes, on which humanity relies upon to meet a host of multidimensional—often contradictory—needs (physical, biological, economic, cultural). As Rockström et al. (2017: 7) have stated: 'World agriculture must now meet social needs and fulfil sustainability criteria that enables food and all other agricultural ecosystem services (i.e., climate stabilization, flood control, support of mental health, nutrition, etc.) to be generated within a safe operating space of a stable and resilient Earth system'. It is precisely within these recalibrated agricultural goals that aquaponics technology must be developed.

16.5 Aquaponic Potential or Misplaced Hope?

Contemporary aquaponic research has shown keen awareness of particular concerns raised in the Anthropocene problematic. Justifications for aquaponic research have tended to foreground the challenge of food security on a globe with an increasing human population and ever strained resource base. For instance, König et al. (2016) precisely situate aquaponics within the planetary concerns of Anthropocene discourse when they state: ‘Assuring food security in the twenty-first century within sustainable planetary boundaries requires a multi-faceted agro-ecological intensification of food production and the decoupling from unsustainable resource use’. Towards these important sustainability goals, it is claimed that aquaponic technology shows much promise (Goddek et al. 2015). The innovative enclosed systems of aquaponics offer an especially alluring convergence of potential resolutions that could contribute towards a more sustainable future.

Proponents of aquaponics often stress the ecological principles at the heart of this emerging technology. Aquaponic systems harness the positive potential of a more or less simple ecosystem, in order to reduce the use of finite inputs whilst simultaneously reducing waste by-products and other externalities. On these grounds, aquaponic technology can be viewed as a primary example of ‘sustainable intensification’ (Garnett et al. 2013) or, more precisely, as a form of ‘ecological intensification’ since its founding principles are based on the management of service-providing organisms towards quantifiable and direct contributions to agricultural production (Bommarco et al. 2013). From this agroecological principle flow a great number of potential sustainability benefits. Chapters 1 and 2 of this book do an exemplary job of highlighting these, detailing the challenges faced by our food system and situating aquaponics science as the potential locus for a range of sustainability and food security interventions. There is no need to repeat these points again, but it is worth noting this perceived convergence of potential resolutions is what drives research and strengthens the ‘conviction that this technology has the potential to play a significant role in food production in the future’ (7) (Junge et al. 2017).

However, despite the considerable claims made by its proponents, the future of aquaponics is less than certain. Just what kind of role aquaponics might play in transitions to sustainable food provision is still largely up for debate—crucially, we must stress, *the publication of sustainability and food security outcomes of aquaponic systems remain conspicuous by their absence across Europe* (König et al. 2018). On paper, the ‘charismatic’ attributes of aquaponics ensure that it can easily be presented as a ‘silver bullet’ type of innovation that gets to the heart of our food system’s deepest sustainability and food security issues (Brooks et al. 2009). Such images have been able to garner considerable attention for aquaponics far beyond the confines of academic research—consider, for instance, the significant production of online aquaponic ‘hype’ in comparison to similar fields, usefully pointed out by Junge et al. (2017). It is here we may take time to point out the relationship between the perceived potential of aquaponics and ‘techno-optimism’.

The introduction of every new technology is accompanied by myths that spur further interest in that technology (Schoenbach 2001). Myths are circulated amongst early adopters and are picked up by the general media often long before the scientific community has time to thoroughly analyse and answer to their claims. Myths, as Schoenbach states (2001, 362), are widely believed because they 'comprise a clear-cut and convincing explanation of the world'. These powerful explanations are able to energise and align individual, community and also institutional action towards particular ends. The 'beauty' of aquaponics, if we can call it that, is that the concept can often render down the complexity of sustainability and food security issues into clear, understandable and scalable systems metaphors. The ubiquitous image of the aquaponic cycle—water flowing between fish, plants and bacteria—that elegantly resolves food system challenges is exemplary here. However, myths on technology, whether optimistic or pessimistic, share a techno-deterministic vision of the relation between technology and society (Schoenbach 2001). Within the techno-deterministic vision of technology, it is the technology that causes important changes in society: if we manage to change the technology, we thus manage to change the world. Regardless whether the change is for the better (techno-optimism) or the worse(technophobia), the technology by itself creates an effect.

Techno-determinist views have been thoroughly critiqued on sociological, philosophical (Bradley 2011), Marxist (Hornborg 2013), material-semiotic (Latour 1996) and feminist (Haraway 1997) grounds. These more nuanced approaches to technological development would claim that technology by itself does not bring change to society; it is neither inherently good nor bad but is always embedded within society's structures, and it is those structures that enable the use and effect of the technology in question. To one degree or another, technology is an emergent entity, the effects of which we cannot know in advance (de Laet and Mol 2000). This might seem like an obvious point, but techno-determinism remains a strong, if often latent, feature within our contemporary epistemological landscape. Our innovation-driven, technological societies are maintained by discursive regimes that hold on to the promise of societal renewal through technological advancement (Lave et al. 2010). Such beliefs have been shown to have an important normative role within expert communities whether they be scientists, entrepreneurs or policymakers (Franklin 1995; Soini and Birkeland 2014).

The rise of aquaponics across Europe is intertwined with specific interests of various actors. We can identify at least five societal processes that led to the development of aquaponics: (a) interest of public authorities in funding high-tech solutions for problems of sustainability; (b) venture capital financing, motivated by the successes in IT startups, looking for 'the next big thing' that will perhaps discover the new 'unicorn' (startup companies valued at over $1 billion); (c) mass media event-focused interest in snapshot reporting on positive stories of new aquaponics startups, fuelled by the public relations activities of these startups, with rare media follow-up reporting on the companies that went bust; (d) internet-supported growth of enthusiastic, do-it-yourself aquaponics communities, sharing both sustainability values and love for tinkering with new technology; (e) interests of urban developers to find economically viable solutions for vacant urban spaces and greening of urban space; and (f) research communities focused on developing technological solutions to impending sustainability and food security problems. To a greater or lesser degree, the spectre of techno-optimistic hope permeates the development of aquaponics.

Although the claims of techno-optimist positions are inspiring and able to precipitate the investment of money, time and resources from diverse actors, the potential for such standpoints to generate justice and sustainability has been questioned on scales from local (Leonard 2013) and regional issues (Hultman 2013) to global imperatives (Hamilton 2013). And it is at this point, we might consider the ambitions of our own field. A good starting point would be the 'COST action FA1305', which has been an important facilitator of Europe's aquaponic research output over recent years, with a number of publications acknowledging the positive impact of the action in enabling research (Miličić et al. 2017; Delaide et al. 2017; Villarroel et al. 2016). Like all COST actions, this EU-funded transnational networking instrument has acted as a hub for aquaponic research in Europe, galvanising and broadening the traditional networks amongst researchers by bringing together experts from science, experimental facilities and entrepreneurs. The original mission statement of COST action FA1305 reads as follows:

> *Aquaponics has a key role to play in food provision and tackling global challenges such as water scarcity, food security, urbanization, and reductions in energy use and food miles.* The EU acknowledges these challenges through its Common Agriculture Policy and policies on Water Protection, Climate Change, and Social Integration. A European approach is required in the globally emerging aquaponics research field building on the foundations of Europe's status as a global centre of excellence and technological innovation in the domains of aquaculture and hydroponic horticulture. The EU Aquaponics Hub aims to the development of aquaponics in the EU, by leading the research agenda through the creation of a networking hub of expert research and industry scientists, engineers, economists, aquaculturists and horticulturalists, and contributing to the training of young aquaponic scientists. The EU Aquaponics Hub focuses on three primary systems in three settings; (1) "cities and urban areas" – urban agriculture aquaponics, (2) "developing country systems" – devising systems and technologies for food security for local people and (3) "industrial scale aquaponics" – *providing competitive systems delivering cost effective, healthy and sustainable local food in the EU*. (http://www.cost.eu/COST_Actions/fa/FA1305, 12.10.2017, emphasis added).

As the mission statement suggests, from the outset of COST action FA1305, high levels of optimism were placed on the role of aquaponics in tackling sustainability and food security challenges. The creation of the COST EU Aquaponics Hub was to 'provide a necessary forum for 'kick-starting' aquaponics as a serious and potentially viable industry for sustainable food production in the EU and the world' (COST 2013). Indeed, from the authors' own participation within COST FA1305, our lasting experience was without doubt one of being part of a vibrant, enthused and highly skilled research community that were more or less united in their ambition to make aquaponics work towards a more sustainable future. Four years down the line since the Aquaponic Hub's mission statement was issued, however, the sustainability and food security potential of aquaponics remains just that—potential. At present it is uncertain what precise role aquaponics can play in Europe's future food system (König et al. 2018).

The commonly observed narrative that aquaponics provides a sustainable solution to the global challenges agriculture faces unveils a fundamental misconception of what it is actually capable to achieve. The plant side of aquaponics is horticulture, not agriculture, producing vegetables and leafy greens with high water content and low nutritional value compared to the staple foods agriculture on farmland produces. A quick comparison of current agricultural area, horticultural area and protected horticultural area, 184.332 km^2, 2.290 km^2 (1,3%) and 9,84 km^2 (0,0053%), in Germany, reveals the flaw in the narrative. Even if considering a much higher productivity in aquaponics through the utilisation of controlled environment systems, aquaponics is not even close to having the potential to make a real impact on agricultural practice. This becomes even more obvious when the ambition to be a 'food system of the future' ends in the quest for high-value crops (e.g. microgreens) that can be marketed as gourmet gastronomy.

It is well known that the development of sustainable technology is characterised by uncertainties, high risks and large investments with late returns (Alkemade and Suurs 2012). Aquaponics, in this regard, is no exception; only handful commercially operating systems exist across Europe (Villarroel et al. 2016). There appears considerable resistance to the development of aquaponic technology. Commercial projects have to contend with comparatively high technological and management complexity, significant marketing risks, as well as an uncertain regulatory situation that until now persists (Joly et al. 2015). Although it is difficult to pin down the rate of startup failure, the short history of commercial aquaponics across Europe might well be summed up as 'Small successes and big failures' (Haenen 2017). It is worth pointing out also that the pioneers already involved in aquaponics at the moment across Europe are unclear if their technology is bringing about any improvements in sustainability (Villarroel et al. 2016). Recent analysis from König et al. (2018) has shown how the challenges to aquaponics development derive from a host of structural concerns, as well as the technology's inherent complexity. Combined, these factors result in a high-risk environment for entrepreneurs and investors, which has produced a situation whereby startup facilities across Europe are forced to focus on production, marketing and market formation over the delivery of sustainability credentials (König et al. 2018). Aside from the claims of great potential, the sombre reality is that it remains to be seen just what impact aquaponics can have on the entrenched food production and consumption regimes operating in contemporary times. The place for aquaponic technology in the transition towards more sustainable food systems, it seems, has no guarantee.

Beyond the speculation of techno-optimism, aquaponics has emerged as a highly complex food production technology that holds potential but is faced with steep challenges. In general, there exists a lack of knowledge about how to direct research activities to develop such technologies in a way that preserves their promise of sustainability and potential solutions to pressing food system concerns (Elzen et al. 2017). A recent survey conducted by Villarroel et al. (2016) found that from

68 responding aquaponic actors spread across 21 European countries, 75% were involved in research activities and 30.8% in production, with only 11.8% of those surveyed actually selling fish or plants in the past 12 months. It is clear that the field of aquaponics in Europe is still mainly shaped by actors from research. In this developmental environment, we believe the next phase of aquaponic research will be crucial to developing the future sustainability and food security potential of this technology.

Interviews (König et al. 2018) and the quantitative surveys (Villarroel et al. 2016) of the European aquaponic field have indicated there is mixed opinion regarding the vision, motivations and expectations about the future of aquaponics. In light of this, Konig et al. (2018) have raised concerns that a diversity of visions for aquaponic technology might hinder the coordination between actors and ultimately disrupt the development of 'a realistic corridor of acceptable development paths' for the technology (König et al. 2018). From an innovation systems perspective, emergent innovations that display an unorganised diversity of visions can suffer from 'directionality failure' (Weber and Rohracher 2012) and ultimately fall short of their perceived potentials. Such perspectives run in line with positions from sustainability science that stress the importance of 'visions' for creating and pursuing desirable futures (Brewer 2007). In light of this, we offer up one such vision for the field of aquaponics. We argue that aquaponics research must refocus on a radical sustainability and food security agenda that is fit for the impending challenges faced in the Anthropocene.

16.6 Towards a 'Sustainability First' Paradigm

As we saw earlier, it has been stressed that the goal to move towards sustainable intensification grows from the acknowledgment of the limits of the conventional agricultural development paradigm and its systems of innovation. Acknowledging the need for food system innovations that exceed the traditional paradigm and that can account for the complexity arising from sustainability and food security issues, Fischer et al. (2007) have called for no less than 'a new model of sustainability' altogether. Similarly, in their recent plea for global efforts towards sustainable intensification, Rockström et al. (2017) have pointed out that a paradigm shift in our food system entails challenging the dominant research and development patterns that maintain the 'productivity first' focus whilst subordinating sustainability agendas to a secondary, 'mitigating' role. Instead, they call for a reversal of this paradigm so that 'sustainable principles become the *entry point* for generating productivity enhancements'. Following this, we suggest a *sustainability first* vision for aquaponics as one possible orientation that can both offer coherence to the field and guide its development towards the proclaimed goals of sustainability and food security.

As with most calls for sustainability, our *sustainability first* proposal might sound rather obvious and unchallenging at first glance, if not completely redundant—surely, we could say, aquaponics is all about sustainability. But history would remind us that making sustainability claims is an agreeable task, whereas securing sustainability outcomes is far less certain (Keil 2007). As we have argued, the 'sustainability' of aquaponics currently exists as potential. Just how this potential translates into sustainability outcomes must be a concern for our research community.

Our 'sustainability first' proposal is far from straightforward. First and foremost, this proposal demands that, if our field is to justify itself on the grounds of sustainability, we must get to grips with the nature of sustainability itself. In this regard, we feel there is much to be learned from the growing arena of sustainability science as well as Science and Technology Studies (STS). We will find that maintaining a sustainability focus within aquaponic research represents a potentially huge shift in the direction, composition and ambition of our research community. Such a task is necessary if we are to direct the field towards coherent and realistic goals that remain focussed on sustainability and food security outcomes that are relevant for the Anthropocene.

Taking sustainability seriously is a massive challenge. This is because, at its core, sustainability is fundamentally an *ethical* concept raising questions about the value of nature, social justice, responsibilities to future generations, etc. and encompasses the multidimensional character of human-environment problems (Norton 2005). As we discussed earlier, the sustainability thresholds that might be drawn up concerning agricultural practices are diverse and often cannot be reconciled in entirety, obligating the need for 'trade-offs' (Funtowicz and Ravetz 1995). Choices have to be made in the face of these trade-offs and most often the criteria upon which such choices are based depend not only upon scientific, technical or practical concerns but also on norms and moral values. It goes without saying, there is little consensus on how to make these choices nor is there greater consensus on the norms and moral values themselves. Regardless of this fact, inquiries into values are largely absent from the mainstream sustainability science agenda, yet as Miller et al. (2014) assert, 'unless the values [of sustainability] are understood and articulated, the unavoidable political dimensions of sustainability will remain hidden behind scientific assertions'. Such situations prevent the coming together of and democratic deliberation between communities—a certain task for achieving more sustainable pathways.

Taking note of the prominent place of values in collective action towards sustainability and food security, scholars from the field of science and technology studies have highlighted that rather than be treated as an important externality to research processes (often dealt with separately or after the fact), values must be moved upstream in research agendas (Jasanoff 2007). When values become a central part of sustainability research, along comes the acknowledgement that decisions can no longer be based on technical criteria alone. This has potentially huge impacts on the research process, because traditionally what might have been regarded as the sole remit of 'expert knowledge' must now be opened up to other knowledge streams (for instance, 'lay', indigenous and practitioner knowledge) with all the epistemological difficulty this entails (Lawrence 2015). In response to these problems, sustainability science has emerged as a field that aims to transcend disciplinary boundaries and seeks to involve non-scientists in solution-oriented, context-determined, research processes that are focused on outcome generation (Miller et al. 2014).

A key question in these discussions is knowledge. Sustainability problems are often caused by the complex interplay of diverse social–ecological factors, and the knowledge needed for effectively governing these challenges has become progressively more dispersed and specialised (Ansell and Gash 2008). The knowledge required for understanding how sustainability concerns hang together is too complex to be organised by a single body and results in the need to integrate different types of knowledge in new ways. This is certainly the case for our own field: like other modes of sustainable intensification (Caron et al. 2014), aquaponic systems are characterised by inherent complexity (Junge et al. 2017) which places great emphasis on new forms of knowledge production (FAO 2013). Complexity of aquaponic systems derives not only from their 'integrated' character but stems also from the wider economic, institutional and political structures that impact the delivery of aquaponics and its sustainability potential (König et al. 2016). Developing solutions towards sustainable aquaponic food systems may well involve contending with diverse realms of understanding from engineering, horticultural, aquacultural, microbiological, ecological, economic and public health research, to the practical and experiential knowledge concerns of practitioners, retailers and consumers. What this amounts to is not just a grouping together of ideas and positions, but entails developing entirely novel modes of knowledge production and an appreciation to bridge 'knowledge gaps' (Caron et al. 2014). Abson et al. (2017) have identified three key requirements of new forms of knowledge production that can foster sustainability transformations: (i) the explicit inclusion of values, norms and context characteristics into the research process to produce 'socially robust' knowledge; (ii) mutual learning processes between science and society, involving a rethink of the role of science in society; and (iii) a problem- and solution-oriented research agenda. Drawing upon these three insights can help our field develop what we call a 'critical sustainability knowledge' for aquaponics. Below we discuss three areas our research community can address that we consider crucial to unlocking the sustainability potential of aquaponics: partiality, context and concern. Developing an understanding of each of these points will help our field pursue a solution-oriented approach for aquaponic sustainability and food security outcomes.

16.7 'Critical Sustainability Knowledge' for Aquaponics

16.7.1 Partiality

Despite contemporary accounts of sustainability that underline its complex, multidimensional and contested character, in practice, much of the science that engages with sustainability issues remains fixed to traditional, disciplinary perspectives and actions (Miller et al. 2014). Disciplinary knowledge, it must be said, has obvious value and has delivered huge advances in understanding since antiquity. Nevertheless, the appreciation and application of sustainability issues through traditional disciplinary channels has been characterised by the historic failure to facilitate the deeper societal change needed for issues such as the one we contend with here—the sustainable transformation of the food system paradigm (Fischer et al. 2007).

The articulation of sustainability problems through traditional disciplinary channels often leads to ‘atomised’ conceptualisations that view biophysical, social and economic dimensions of sustainability as compartmentalised entities and assume these can be tackled in isolation (e.g. Loos et al. 2014). Instead of viewing sustainability issues as a convergence of interacting components that must be addressed together, disciplinary perspectives often promote ‘techno-fixes’ to address what are often complex multidimensional problems (e.g. Campeanu and Fazey 2014). A common feature of such framings is that they often imply that sustainability problems can be resolved without consideration of the structures, goals and values that underpin complex problems at deeper levels, typically giving little consideration to the ambiguities of human action, institutional dynamics and more nuanced conceptions of power.

The practice of breaking a problem down into discrete components, analysing these in isolation and then reconstructing a system from interpretations of the parts has been a hugely powerful methodological insight that traces its history back to the dawn of modernity with the arrival of Cartesian reductionism (Merchant 1981). Being a key tenet of the production of objective knowledge, this practice forms the bedrock of most disciplinary effort in the natural sciences. The importance of objective knowledge, of course, is in that it provides the research community with ‘facts’; precise and reproducible insights about generally dispersed phenomena. The production of facts was the engine room of innovation that propelled the Green Revolution. Science fuelled ‘expert knowledge’ and provided penetrating information about dynamics in our food production systems that remained invariant through change in time, space or social location. Building a catalogue of this kind of knowledge, and deploying it as what Latour (1986) calls ‘immutable mobiles’, formed the basis of the universal systems of monocropping, fertilisation and pest control that characterise the modern food system (Latour 1986).

But this form of knowledge production has weaknesses. As any scientist knows, in order to gain significant insights, this method must be strictly applied. It has been shown that this knowledge production is ‘biased toward those elements of nature which yield to its method and toward the selection of problems most tractable to solutions with the knowledge thereby produced’ (Kloppenburg 1991). A clear example of this would be our imbalanced food security research agenda that heavily privileges production over conservation, sustainability or food sovereignty issues (Hunter et al. 2017). Most high-profile work on food security concentrates on production (Foley et al. 2011), emphasising material flows and budgets over deeper issues such as the structures, rules and values that shape food systems. The simple fact is that because we know more about material interventions it is easier to design, model and experiment on these aspects of the food system. As Abson et al. (2017: 2) point out: 'Much scientific lead sustainability applications assume some of the most challenging drivers of unsustainability can be viewed as "fixed system properties" that can be addressed in isolation'. In pursuing the paths along which experimental success is most often realised, 'atomised' disciplinary approaches neglect those areas where other approaches might prove rewarding. Such epistemological 'blind spots' mean that sustainability interventions are often geared towards highly tangible aspects that may be simple to envisage and implement, yet have weak potential for 'leveraging' sustainable transition or deeper system change (Abson et al. 2017). Getting to grips with the limits and partialities of our disciplinary knowledge is one aspect that we stress when we claim the need to develop a 'critical sustainability knowledge' for aquaponics.

Viewed from disciplinary perspectives the sustainability credentials of aquaponic systems can be more or less simple to define (for instance, water consumption, efficiency of nutrient recycling, comparative yields, consumption of non-renewable inputs, etc.). Indeed, the more narrowly we define the sustainability criteria, the more straightforward it is to test such parameters, and the easier it is to stamp the claim of sustainability on our systems. The problem is that we can engineer our way to a form of sustainability that only few might regard as sustainable. To paraphrase Kläy et al. (2015), when we transform our original concern of how to realise a sustainable food system into a 'matter of facts' (Latour 2004) and limit our research effort to the analysis of these facts, we subtly but profoundly change the problem and direction of research. Such an issue was identified by Churchman (1979:4–5) who found that because science addresses mainly the identification and the solution of problems, and not the systemic and related ethical aspects, there is always the risk that the solutions offered up may even increase the unsustainability of development—what he called the 'environmental fallacy' (Churchman 1979).

We might raise related concerns for our own field. Early research in aquaponics attempted to answer questions concerning the environmental potential of the technology, for instance, regarding water discharge, resource inputs and nutrient recycling, with research designed around small-scale aquaponic systems. Although admittedly narrow in its focus, this research generally held sustainability concerns in focus. Recently, however, we have detected a change in research focus. This is raised in Chap. 1 of this book, whose authors share our own view, observing that research 'in recent years has increasingly shifted towards economic feasibility in order to make aquaponics more productive for large-scale farming applications'. Discussions, we have found, are increasingly concerned with avenues of efficiency and profitability that often fix the potential of aquaponics against its perceived competition with other large-scale production methods (hydroponics and RAS). The argument appears to be that only when issues of system productivity are solved, through efficiency measures and technical solutions such as optimising growth conditions of plants and fish, aquaponics becomes economically competitive with other industrial food production technologies and is legitimated as a food production method.

We would certainly agree that economic viability is an important constituent of the long-term resilience and sustainability potential of aquaponics. However, we would caution against too narrowly defining our research ethic—and indeed, the future vision of aquaponics—based on principles of production and profit alone. We worry that when aquaponic research is limited to efficiency, productivity and market competitiveness, the old logics of the Green Revolution are repeated and our claims to food security and sustainability become shallow. As we saw earlier, productionism has been understood as a process in which a logic of production overdetermines other activities of value within agricultural systems (Lilley and Papadopoulos 2014). Since sustainability inherently involves a complex diversity of values, these narrow avenues of research, we fear, risk the articulation of aquaponics within a curtailed vision of sustainability. Asking the question 'under what circumstances can aquaponics outcompete traditional large-scale food production methods?' is not the same as asking 'to what extent can aquaponics meet the sustainability and food security demands of the Anthropocene?'.

16.7.2 Context

Knowledge production through traditional disciplinary pathways involves a loss of context that can narrow our response to complex sustainability issues. The multidimensional nature of food security implies that 'a single globally valid pathway to sustainable intensification does not exist' (Struik and Kuyper 2014). The physical, ecological and human demands placed on our food systems are context-bound and, as such, so are the sustainability and food security pressures which flow from these needs. Intensification requires contextualisation (Tittonell and Giller 2013). Sustainability and food security are outcomes of 'situated' practices, and cannot be extracted from the idiosyncrasies of context and 'place' that are increasingly seen as important factors in the outcomes of such (Altieri 1998; Hinrichs 2003; Reynolds et al. 2014). Added to this, the Anthropocene throws up an added task: localised forms of knowledge must be coupled with 'global' knowledge to produce sustainable solutions. The Anthropocene problematic places a strong need upon us to recognise the interconnectedness of the world food system and our globalised place within it: The particular way sustainable intensification is achieved in one part of the planet is likely to have ramifications elsewhere (Garnett et al. 2013). Developing a 'critical sustainability knowledge' means opening up to the diverse potentials and restraints that flow from contextualised sustainability concerns.

One of the main ruptures proposed by ecological intensification is the movement away from the chemical regulation that marked the driving force of agricultural development during the industrial revolution and towards biological regulation. Such a move reinforces the importance of local contexts and specificities. Although dealing most often with traditional, small-holder farming practices, agroecological methods have shown how context can be attended to, understood, protected and celebrated in its own right (Gliessman 2014). Studies of 'real' ecosystems in all their contextual complexity may lead to a 'feeling for the ecosystem'—critical to the pursuit of understanding and managing food production processes (Carpenter 1996).

The relevance of agroecological ideas need not be restricted to 'the farm'; the nature of closed-loop aquaponics systems demands a 'balancing' of co-dependent ecological agents (fish, plants, microbiome) within the limits and affordances of each particular system. Although the microbiome of aquaponics systems has only just begun to be analysed (Schmautz et al. 2017), complexity and dynamism is expected to exceed Recirculating Aquaculture Systems, whose microbiology is known to be affected by feed type and feeding regime, management routines, fish-associated microflora, make-up water parameters and selection pressure in the biofilters (Blancheton et al. 2013). What might be regarded as 'simple' in comparison to other farming methods, the ecosystem of aquaponics systems is nevertheless dynamic and requires care. Developing an 'ecology of place', where context is intentionality and carefully engaged with, can serve as a creative force in research, including scientific understanding (Thrift 1999; Beatley and Manning 1997).

The biophysical and ecological dynamics of aquaponic systems are central to the whole conception of aquaponics, but sustainability and food security potentials do not derive solely from these parameters. As König et al. (2016) point out, for aquaponic systems: 'different settings potentially affects the delivery of all aspects of sustainability: economic, environmental and social' (König et al. 2016). The huge configurational potential of aquaponics—from miniature to hectares, extensive to intensive, basic to high-tech systems—is quite atypical across food production technologies (Rakocy et al. 2006). The integrative character and physical plasticity of aquaponic systems means that the technology can be deployed in a wide variety of applications. This, we feel, is precisely the strength of aquaponic technology. Given the diverse and heterogeneous nature of sustainability and food security concerns in the Anthropocene, the great adaptability, or even 'hackability' (Delfanti 2013), of aquaponics offers much potential for developing 'custom-fit' food production (Reynolds et al. 2014) that is explicitly tailored to the environmental, cultural and nutritional demands of place. Aquaponic systems promise avenues of food production that might be targeted towards local resource and waste assimilative limits, material and technological availability, market and labour demands. It is for this reason that the pursuit of sustainability outcomes may well involve different technological developmental paths dependent upon locale (Coudel et al. 2013). This is a point that is beginning to receive increasing acknowledgement, with some commentators claiming that the urgency of global sustainability and food security issues in the Anthropocene demand an open and multidimensional approach to technological innovation. For instance, Foley et al. (2011:5) state: 'The search for agricultural solutions should remain technology neutral. There are multiple paths to improving the production, food security and environmental performance of agriculture, and we should not be locked into a single approach a priori, whether it be conventional agriculture, genetic modification or organic farming' (5) (Foley et al. 2011). We would highlight this point for aquaponics, as König et al. (2018: 241) have already done: 'there are several sustainability problems which aquaponics could address, but which may be impossible to deliver in one system setup. Therefore, future pathways will always need to involve a diversity of approaches'.

But the adaptability of aquaponics might be seen as a double-edged sword. Inspiration for specific 'tailor-made' sustainability solutions brings with it the difficulty of generalising aquaponic knowledge for larger-scale and repeatable purposes. Successful aquaponics systems respond to local specificities in climate, market, knowledge, resources, etc. (Villarroel et al. 2016; Love et al. 2015; Laidlaw and Magee 2016), but this means that changes at scale cannot easily proceed from the fractal replication of non-reproducible local success stories. Taking similar issues as these into account, other branches of ecological intensification research have suggested that the expression 'scaling up' must be questioned (Caron et al. 2014). Instead, ecological intensification is beginning to be viewed as a transition of multi-scalar processes, all of which follow biological, ecological, managerial and political 'own rules', and generate unique trade-off needs (Gunderson 2001).

Understanding and intervening in complex systems like this presents huge challenges to our research, which is geared towards the production of 'expert knowledge', often crafted in the lab and insulated from wider structures. The complex problem of food security is fraught with uncertainties that cannot be adequately resolved by resorting to the puzzle-solving exercises of Kuhnian 'normal science' (Funtowicz and Ravetz 1995). The necessity to account for 'specificity' and 'generality' in complex sustainably issues produces great methodological, organisational and institutional difficulties. The feeling is that to meet contextualised sustainability and food security goals, 'universal' knowledge must be connected to 'place-based' knowledge (Funtowicz and Ravetz 1995). For Caron et al. (2014), this means that 'scientists learn to continually go back and forth...' between these two dimensions, '. . .both to formulate their research question and capitalize their results. . . Confrontation and hybridization between heterogeneous sources of knowledge is thus essential' (Caron et al. 2014). Research must be opened up to wider circles of stakeholders and their knowledge streams.

Given the huge challenge on all accounts that such a scheme entails, a tempting resolution might be found in the development of more advanced 'environment-controlled' aquaponic farming techniques. Such systems work by cutting out external influences in production, maximising efficiency by minimising the influence of suboptimal, location-specific variables (Davis 1985). But we question this approach on a number of accounts. Given that the impulse of such systems lies in buffering food production from 'localised inconsistencies', there is always a risk that the localised sustainability and food security needs might also be externalised from system design and management. Cutting out localised anomalies in the search of the 'perfect system' must certainly offer tantalising efficiency potentials on paper, but we fear this type of problem-solving bypasses the specificity-generality problematic of sustainability issues in the Anthropocene without confronting them. Rather than a remedy, the result may well be an extension of the dislocated, 'one size fits all' approach to food production that marked the Green Revolution.

Current aquaponics research that follows either of the informal schools of 'decoupling' or 'closing the cycle' might well be an example of such framings. By pushing the productivity limits of either production side—aquaculture or hydroculture—inherent operational compromises of the ecological aquaponic principle become more apparent and become viewed as barriers to productivity that must be overcome. Framing the aquaponic problem like this results in solutions that involve more technology: patented one-way valves, condensation traps, high-tech oxygenators, LED lighting, additional nutrient dispensers, nutrient concentrators and so on. These directions repeat the knowledge dynamic of modern industrial agriculture that overly concentrated the expertise and power of food production systems into the hands of applied scientists engaged in the development of inputs, equipment and remote system management. We are unsure of how such technocratic measures might fit within a research ethic that places sustainability first. This is not an argument against high-tech, closed environment systems; we simply hope to emphasise that within a *sustainability first* paradigm, our food production technologies must be justified on the grounds of generating context-specific sustainability and food security outcomes.

Understanding that sustainability cannot be removed from the complexities of context or the potentials of place is to acknowledge that 'expert knowledge' alone cannot be held as guarantor of sustainable outcomes. This strikes a challenge to modes of centralised knowledge production based on experiments under controlled conditions and the way science might contribute to the innovation processes (Bäckstrand 2003). Crucial here is the design of methodological systems that ensure both the robustness and genericity of scientific knowledge is maintained along with its relevance to local conditions. Moving to conceptions like this requires a huge shift in our current knowledge production schemes and not only implies better integration of agronomic with human and political sciences but suggests a path of knowledge co-production that goes well beyond 'interdisciplinarity' (Lawrence 2015).

Here it is important to stress Bäckstrand's (2003: 24) point that the incorporation of lay and practical knowledge in scientific processes 'does not rest on the assumption that lay knowledge is necessarily "truer", "better" or "greener"'. Rather, as Leach et al. (2012: 4) point out, it stems from the idea that 'nurturing more diverse approaches and forms of innovation (social as well as technological) allows us to respond to uncertainty and surprise arising from complex, interacting biophysical and socioeconomic shocks and stresses'. Faced with the uncertainty of future environmental outcomes in the Anthropocene, a multiplicity of perspectives can prevent the narrowing of alternatives. In this regard, the potential wealth of experimentation occurring in 'backyard' and community projects across Europe represents an untapped resource which has until now received little attention from research circles. 'The small-scale sector...' Konig et al. (2018: 241) observe, '...shows optimism and a surprising degree of self-organization over the internet. There might be room for creating additional social innovations'. Given the multidimensional nature of issues in the Anthropocene, grassroots innovations, like the backyard aquaponics sector, draw from local knowledge and experience and work towards social and organisational forms of innovation that are, in the eyes of Leach et al. (2012: 4), 'at least as crucial as advanced science and technology'. Linking with community aquaponics groups potentially offers access to vibrant local food groups, local government and local consumers who are often enthusiastic about the prospects of collaborating with researchers. It is worth noting that in an increasingly competitive funding climate, local communities offer a well of resources—intellectual, physical and monetary—that often get overlooked but which can supplement more traditional research funding streams (Reynolds et al. 2014).

As we know, currently, large-scale commercial projects face high marketing risks, strict financing deadlines, as well as high technological and management complexity that makes collaboration with outside research organisations difficult. Because of this, we would agree with König et al. (2018) who find advantages for experimentation with smaller systems that have reduced complexity and are tied down by fewer legal regulations. The field must push to integrate these organisations within participatory, citizen-science research frameworks, allowing academic research to more thoroughly mesh with forms of aquaponics working in the world. In the absence of formalised sustainability measures and protocols, aquaponic enterprises risk legitimation issues when their produce is marketed on claims of sustainability. One clear possibility of participatory research collaborations would be the joint production of much needed 'situation-specific sustainability goals' for facilities that could form the 'basis for system design' and bring 'a clear marketing strategy' (König et al. 2018). Working towards outcomes like these might also improve the transparency, legitimacy and relevance of our research endeavours (Bäckstrand 2003).

The European research funding climate has begun to acknowledge the need to shift research orientation by including the requirement in recent project funding calls of implementing the so-called 'living labs' into research projects (Robles et al. 2015). Starting in June 2018, the Horizon 2020 project proGIreg (H2020-SCC-2016-2017) is going to include a living lab for the exemplary implementation of the so-called nature-based systems (NBS), one of which will be a community designed, community-built and community-operated aquaponic system in a passive solar greenhouse. The project, with 36 partners in 6 countries, aims to find innovative ways to productively utilise green infrastructure of urban and peri-urban environments, building upon the co-production concepts developed in its currently running sibling project, CoProGrün.

The researchers' working packages regarding the aquaponic part of the project are going to be threefold. One part will be about raising the so-called technology readiness level (TRL) of aquaponics, a research task without explicit collaboration with laypersons and the community. Resource utilisation of current aquaponic concepts and resource optimisation potential of additional technical measures are the core objectives of this task. While at first glance this task seems to follow the above-criticised paradigm of productivity and yield increase, evaluation criteria for different measures will include more multifaceted aspects such as ease of implementation, understandability, appropriateness and transferability. A second focus will be support of the community planning, building and operational processes, which seeks to integrate objective knowledge and practitioner knowledge generation. A meta-objective of this process will be the observation and the moderation of the relevant community collaboration and communication processes. In this approach, moderation is actively expected to alter observation, illustrating a deviation from the traditional research routines of fact building and repeatability. A third package encompasses research on political, administrative, technical and financial obstacles. The intention here is to involve a wider collection of stakeholders, from politicians and decision-makers to planners, operators and neighbours, with research structures developed to bring together each of these specific perspectives. Hopefully, this more holistic method opens a path to the 'sustainability first' approach proposed in this chapter.

16.7.3 Concern

Recognising aquaponics as a multifunctional form of food production faces large challenges. As has been discussed, grasping the notion of 'multifunctional agriculture' is more than just a critical debate on what constitutes 'post-productionism' (Wilson 2001); this is because it seeks to move understandings of our food system to positions that better encapsulates the diversity, nonlinearity and spatial heterogeneity that are acknowledged as key ingredients to a sustainable and just food system. It is important to remember that the very notion of 'multifunctionality' in agriculture arose during the 1990s as 'a consequence of the undesired and largely unforeseen environmental and societal consequences and the limited cost-effectiveness of the European Common Agricultural Policy (CAP), which mainly sought to boost agrarian outputs and the productivity of agriculture' (270) (Cairol et al. 2009). Understanding that our political climates and institutional structures have been unconducive to sustainable change is a point we must not forget. As others have pointed out in adjacent agronomic fields, understanding and unlocking the richness of food production contributions to human welfare and environmental health will necessarily involve a *critical* dimension (Jahn 2013). This insight, we feel, must feature more strongly in aquaponics research.

We chose the word 'concern' here carefully. The word concern carries different connotations to 'critique'. Concern carries notions of anxiety, worry and trouble. Anxiety comes when something disrupts what could be a more healthy or happy or secure existence. It reminds us that to do research in the Anthropocene is to acknowledge our drastically unsettling place in the world. That our 'solutions' always carry the possibility of trouble, whether this be ethical, political or environmental. But concern has more than just negative connotations. To concern also means to 'be about', to 'relate to' and also 'to care'. It reminds us to question what our research is about. How our disciplinary concerns relate to other disciplines as well as wider issues. Crucially, sustainability and food security outcomes require us to care about the concerns of others.

Considerations such as these make up a third aspect of what we mean when we call for a *'Critical sustainability knowledge'* for aquaponics. As a research community, it is crucial that we develop an understanding of the structural factors which impinge upon and restrict the effective social, political and technological innovation of aquaponics. Technical change relies upon infrastructure, financing capacities, market organisations as well as labour and land rights conditions (Röling 2009). When the role of this wider framing is assumed only as an 'enabling environment', often the result is that such considerations are left outside of the research effort. This is a point which serves to easily justify the failure of technology-based, top-down development drives (Caron 2000). In this regard, the techno-optimistic discourse of contemporary aquaponics, in its failure to apprehend wider structural resistance to the development of sustainable innovation, would serve as a case example.

As an important potential form of sustainable intensification, aquaponics needs to be recognised as being embedded in and linked to different social, economic and organisational forms at various scales potentially from household, value chain, food system and beyond including also other political levels. Thankfully, moves towards attending to the wider structural difficulties that aquaponic technology faces have recently been made, with König et al. (2018) offering a view of aquaponics through an 'emerging technological innovation system' lens. König et al. (2018) have shown how the challenges to aquaponics development derive from: (1) system complexity, (2) the institutional setting and (3) the sustainability paradigm it attempts to impact. The aquaponic research field needs to respond to this diagnosis.

The slow uptake and high chance of failure that aquaponics technology currently exhibits is an expression of the wider societal resistance that makes sustainable innovation such a challenge, as well as our inability to effectively organise against such forces. As König et al. (2018) note, the high-risk environment that currently exists for aquaponic entrepreneurs and investors forces startup facilities across Europe to focus on production, marketing and market formation, over the delivery of sustainability credentials. Along these lines, Alkemade and Suurs (2012) remind us, 'market forces alone cannot be relied upon to realize desired sustainability transitions'; rather, they point out, insight into the dynamics of innovation processes is needed if technological change can be guided along more sustainable trajectories (Alkemade and Suurs 2012).

The difficulties aquaponic businesses face in Europe suggest the field currently lacks the necessary market conditions, with 'consumer acceptance'—an important factor enabling the success of novel food system technologies—acknowledged as a possible problem area. From this diagnosis, there has been raised the problem of 'consumer education' (Miličić et al. 2017). Along with this, we would stress that collective education is a key concern for questions of food system sustainability. But accounts like these come with risks. It is easy to fall back on traditional modernist conceptions regarding the role of science in society, assuming that 'if only the public understood the facts' about our technology they would choose aquaponics over other food production methods. Accounts like these assume too much, both about the needs of 'consumers', as well as the value and universal applicability of expert knowledge and technological innovation. There is a need to seek finer-grain and more nuanced accounts of the struggle for sustainable futures that move beyond the dynamic of consumption (Gunderson 2014) and have greater sensitivity to the diverse barriers communities face in accessing food security and implementing sustainable action (Carolan 2016; Wall 2007).

Gaining insight into innovation processes puts great emphasis upon our knowledge-generating institutions. As we have discussed above, sustainability issues demand that science opens up to public and private participatory approaches entailing knowledge co-production. But in terms of this point, it's worth noting that huge challenges lay in store. As Jasanoff (2007: 33) puts it: 'Even when scientists recognize the limits of their own inquiries, as they often do, the policy world, implicitly encouraged by scientists, asks for more research'. The widely held assumption that *more* objective knowledge is the key to bolstering action towards sustainability runs contrary to the findings of sustainability science. Sustainability outcomes are actually more closely tied deliberative knowledge processes: building greater awareness of the ways in which experts and practitioners frame sustainability issues; the values that are included as well as excluded; as well as effective ways of facilitating communication of diverse knowledge and dealing with conflict if and when it arises (Smith and Stirling 2007; Healey 2006; Miller and Neff 2013; Wiek et al. 2012). As Miller et al. (2014) point out, the continuing dependence upon objective knowledge to adjudicate sustainability issues represents the persistence of the modernist belief in rationality and progress that underwrites almost all knowledge-generating institutions (Horkheimer and Adorno 2002; Marcuse 2013).

It is here where developing a critical sustainability knowledge for aquaponics shifts our attention to our own research environments. Our increasingly 'neoliberalised' research institutions exhibit a worrying trend: the rollback of public funding for universities, the increasing pressure to get short-term results, the separation of research and teaching missions, the dissolution of the scientific author, the contraction of research agendas to focus on the needs of commercial actors, an increasing reliance on market take-up to adjudicate intellectual disputes and the intense fortification of intellectual property in the drive to commercialise knowledge, all of which have been shown to impact on the production and dissemination of our research, and indeed all are factors that impact the nature of our science (Lave et al. 2010). One question that must be confronted is whether our current research environments are fit for the examination of complex sustainability and long-term food security targets that must be part of aquaponic research. This is the key point we would like to stress—if sustainability is an outcome of multidimensional collective deliberation and action, our own research endeavours, thoroughly part of the process, must be viewed as something that can be innovated towards sustainability outcomes also. The above-mentioned Horizon 2020 project proGIreg may be an example of some ambitious first steps towards crafting new research environments, but we must work hard to keep the research process itself from slipping out of view. Questions might be raised about how these potentially revolutionary measures of 'living labs' might be implemented from within traditional funding logics. For instance, calls for participatory approaches foreground the conceptual importance of open-ended outcomes, while at the same time requiring the intended spending of such living labs to be predefined. Finding productive ways out of traditional institutional barriers is an ever-present concern.

Our modern research environments can no longer be regarded as having a privileged isolation from the wider issues of society. More than ever our innovation-driven biosciences are implicated in the agrarian concerns of the Anthropocene (Braun and Whatmore 2010). The field of Science and Technology Studies teaches us that technoscientific innovations come with serious ethico-political implication. A 30-year-long discussion in this field has moved well beyond the idea that technologies are simply ‘used’ or ‘misused’ by different socio-political interests after the hardware has been ‘stabilised’ or legitimated through objective experimentation in neutral lab spaces (Latour 1987; Pickering 1992). The ‘constructivist’ insight in STS analyses goes beyond the identification of politics inside labs (Law and Williams 1982; Latour and Woolgar 1986 [1979]) to show that the technologies we produce are not ‘neutral’ objects but are in fact infused with ‘world-making’ capacities and political consequence.

The aquaponics systems we help to innovate are filled with future making capacity, but the consequences of technological innovation are seldom a focus of study. To paraphrase Winner (1993), what the introduction of new artefacts means for people’s sense of self, for the texture of human/nonhuman communities, for qualities of everyday living within the dynamic of sustainability and for the broader distribution of power in society, these have not traditionally been matters of explicit concern. When classic studies (Winner 1986) ask the question ‘Do artefacts have politics?’, this is not only a call to produce more accurate examinations of technology by including politics in accounts of the networks of users and stakeholders, though this is certainly needed; it also concerns us researchers, our modes of thought and ethos that affect the politics (or not) we attribute to our objects (de la Bellacasa 2011; Arboleda 2016). Feminist scholars have highlighted how power relations are inscribed into the very fabric of modern scientific knowledge and its technologies. Against alienated and abstract forms of knowledge, they have innovated key theoretical and methodological approaches that seek to bring together objective and subjective views of the world and to theorise about technology from the starting point of practice (Haraway 1997; Harding 2004). Aware of these points, Jasanoff (2007) calls for the development of what she calls ‘technologies of humility’: ‘Humility instructs us to think harder about how to reframe problems so that their ethical dimensions are brought to light, which new facts to seek and when to resist asking science for clarification. Humility directs us to alleviate known causes of people’s vulnerability to harm, to pay attention to the distribution of risks and benefits, and to reflect on the social factors that promote or discourage learning’.

An important first step for our field to take towards understanding better the political potentials of our technology would be to encourage the expansion of the field out into critical research areas that are currently underrepresented. Across the Atlantic in the US and Canada similar moves like this have already been made, where an interdisciplinary approach has progressively developed into the critical field of political ecology (Allen 1993). Such projects not only aim to combine agriculture and land use patterns with technology and ecology, but furthermore, also emphasise the integration of socioeconomic and political factors (Caron et al. 2014). The aquaponics research community in America has begun to acknowledge the expanding resources of food sovereignty research, exploring how urban communities can be re-engaged with the principles of sustainability, whilst taking more control over their food production and distribution (Laidlaw and Magee 2016). Food sovereignty has become a huge topic that precisely seeks to intervene into food systems that are overdetermined by disempowering capitalist relations. From food sovereignty perspectives, the corporate control of the food system and the commodification of food are seen as predominant threats to food security and the natural environment (Nally 2011). We would follow Laidlaw and Magee's (2016) view that community-based aquaponics enterprises 'represent a new model for how to blend local agency with scientific innovation to deliver food sovereignty in cities'.

Developing a *'critical sustainability knowledge'* for aquaponics means resisting the view that society and its institutions are simply neutral domains that facilitate the linear progression towards sustainable innovation. Many branches of the social sciences have contributed towards an image of society that is infused with asymmetric power relations, a site of contestation and struggle. One such struggle concerns the very meaning and nature of sustainability. Critical viewpoints from wider fields would underline that aquaponics is a technology ripe with both political potential and limitation. If we are serious about the sustainability and food security credentials of aquaponics, it becomes crucial that we examine more thoroughly how our expectations of this technology relate to on-the-ground experience, and in turn, find ways of integrating this back into research processes. We follow Leach et al. (2012) here who insist on the need for finer-grained considerations regarding the performance of sustainable innovations. Apart from the claims, just who or what stands to benefit from such interventions must take up a central place in the aquaponic innovation process. Lastly, as the authors of Chap. 1 have made clear, the search for a lasting paradigm shift will require the ability to place our research into policy circuits that make legislative environments more conducive to aquaponics development and enable larger-scale change. Influencing policy requires an understanding of the power dynamics and political systems that both enable and undermine the shift to sustainable solutions.

16.8 Conclusion: Aquaponic Research into the Anthropocene

The social–biophysical pressures *of* and *on* our food system converge in the Anthropocene towards what becomes seen as an unprecedented task for the global community, requiring 'nothing less than a planetary food revolution' (Rockström et al. 2017). The Anthropocene requires food production innovations that exceed traditional paradigms, whilst at the same time are able to acknowledge the complexity arising from the sustainability and food security issues that mark our times. Aquaponics is one technological innovation that promises to contribute much towards these imperatives. But this emergent field is in an early stage that is characterised by limited resources, market uncertainty, institutional resistance and high risks of failure—an innovation environment where hype prevails over demonstrated outcomes. The aquaponics research community potentially holds an important place in the development path of this technology. As an aquaponics research community, we need to craft viable visions for the future.

We propose one such vision when we call for a 'sustainability first' research programme. Our vision follows Rockström et al.'s (2017) diagnosis that paradigm change requires shifting the research ethic away from traditional productivist avenues so that sustainability becomes the central locus of the innovation process. This task is massive because the multidimensional and context-bound nature of sustainability and food security issues is such that they cannot be resolved solely through technical means. The ethical- and value-laden dimensions of sustainability require a commitment to confront the complexities, uncertainty, ignorance and contestation that ensue such issues. All this places great demands on the knowledge we produce; not only how we distribute and exchange it, but also its very nature.

We propose the aquaponic field needs to pursue a 'critical sustainability knowledge'. When König et al. (2018) ask what sustainability experimentation settings would be needed to enable science, business, policy and consumers to 'answer sustainability questions without repeating the development path of either [RAS or hydroponics]', the point is clear—we need to learn from the failures of the past. The current neoliberal climate is one that consistently opens 'sustainability' discussion up to (mis)appropriation as 'agribusiness mobilises its resources in an attempt to dominate discourse and to make its meaning of "alternative agriculture" the universal meaning' (Kloppenburg 1991). We need to build a critical sustainability knowledge that is wise to the limits of technocratic routes to sustainability, which is sensitive to the political potential of our technologies as well as the structural forms of resistance that limit their development.

A critical sustainability knowledge builds awareness of the limits of its own knowledge pathways and opens up to those other knowledge streams that are often pushed aside in attempts to expand scientific understanding and technological capacity. This is a call for interdisciplinarity and the depth it brings, but it goes further than this. Sustainability and food security outcomes have little impact if they can only be generated in the lab. Research must be contextualised: we need 'to produce and embed scientific knowledge into local innovation systems' (51) (Caron et al. 2014). Building co-productive links with aquaponics communities already existing in society means forging the social and institutional structures that can enable our communities to continually learn and adapt to new knowledge, values, technologies and environmental change. Together, we need to deliberate on the visions and the values of our communities and explore the potential sociotechnical pathways that might realise such visions. Central to this, we need systems of organising and testing the sustainability and food security claims that are made of this technology (Pearson et al. 2010; Nugent 1999) so that greater transparency and legitimation might be brought to the entire field: entrepreneurs, enterprises, researchers and activists alike.

If all this seems like a tall order, that's because it is. The Anthropocene calls for a huge rethink in the way society is being organised, and our food system is central to this. There is a chance, we believe, that aquaponics has a part to play in this. But if our hopes are not to get lost in the hype bubble of hollow sustainability chatter that marks our neoliberal times, we have to demonstrate that aquaponics offers something different. As a final remark, we revisit de la Bellacasa's (2015) point that: 'agricultural intensification is not only a quantitative orientation (yield increase), but entails a "way of life"'. If this is the case, then the pursuit of *sustainable intensification* demands that we find a new way of living. We need sustainability solutions that acknowledge this fact and research communities that are responsive to it.

[1] For instance, consider the following statement issued by Monsanto: 'The main uses of GM crops are to make them insecticide- and herbicide tolerant. They don't inherently increase the yield. They protect the yield'. Quoted in E. Ritch, 'Monsanto Strikes Back at Germany, UCS', Cleantech.com (April 17, 2009). Accessed on July 18, 2009.

[2] Especially important here are the effects of climate change, as well as the 'superweed' phenomenon of increasingly resistant pests that significantly diminish yields.

[3] Productivist discourse invariably ignores Amartya Sen's (1981, 154; Roberts 2008, 263; WFP 2009, 17) classic point that the volume and availability of food alone is not a sufficient explanation for the persistence of world hunger. It is well established that enough food exists to feed in excess of the world's current population (OECD 2009, 21)

[4] Although the calculations are complex and contested, one common estimate is that industrial agriculture requires an average 10 calories of fossil fuels to produce a single calorie of food (Manning 2004), which might rise to 40 calories in beef (Pimentel 1997).

[5] Externalities of our current food system are often ignored or heavily subsidised away. Moore (2015: 187) describes the situation as 'a kind of "ecosystem services" in reverse': 'Today, a billion pounds of pesticides and herbicides are used each year in American agriculture. The long recognized health impacts have been widely studied. Although the translation of such "externalities" into the register of accumulation is imprecise, their scale is impressive, totalling nearly $17 billion in unpaid costs for American agriculture in the early twenty-first century'. On externalities see: Tegtmeier and Duffy (2004).

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