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Viewpoint

Biotechnology or organic? Extensive or intensive? Global or local? A critical review of potential pathways to resolve the global food crisis

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ABSTRACT

While experts agree that poverty, population, energy prices, climate change, and socio-political dynamics undermine global food security, there is no agreement on effective strategies to meet this challenge. For example, some promote “high tech” solutions (e.g. biotechnology) designed to boost yield while others prefer local food systems. To better understand these debates, this article explores four perspectives from the literature: (1) technology to increase food production; (2) equitable food distribution; (3) policies to reduce pollution and waste; and (4) community action to promote sovereign food systems. The paper concludes with recommendations on how food scientists can navigate these controversies to help research and policy making.

1. Introduction – the global food crisis

Many academics and policymakers interested in global food security are concerned that humanity faces a major crisis over the next generation (Foley et al. 2011; Godfray et al. 2010a). Population growth and economic inequality are shaping new global demands for food, while climate change, volatile energy prices, soil erosion, and water scarcity threaten to make food more difficult and more expensive to produce. Meanwhile, technological innovation offers the promise of boosting productivity and ameliorating some of these challenges. Because of these factors, many experts are worried that we face a “perfect storm” of problems; unless we use technology to increase food production, while at the same time decreasing agriculture's impact on the environment, the world may become hungrier, more violent, and more disease-ridden (Beddington, 2009).

But while there is a broad consensus that developing food systems capable of sustainably feeding at least 9 billion people represents a major challenge, there is no agreement as to the best strategies to meet this challenge. For instance, and as will be outlined in detail below, some argue that we need technology, and in particular enhanced biotechnologies, to boost yields and ensure the earth produces enough food for future generations (e.g. Cassman, Grassini, & van Wart, 2010; Fedoroff et al. 2010; Jaggard, Qi, & Ober, 2010).

However, many argue that poverty and a lack of political power are more important in terms of causing hunger and malnutrition than the ability of a region to produce food. In other words, the fact that some people lack that ability to demand food from the market is a larger determinant of food security than harvest or yield (e.g. Sen, 1981). Supporting these arguments are data that show there is

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enough food on the planet for everyone: after accounting for food waste and crops used for bioenergy, there are approximately 2850 dietary calories available on the planet per person per day (FAO, 2015a,b). Nevertheless, approximately 800 million go hungry (FAO, 2015a,b). Even if we assumed that food production remained constant, while our population grows to 9 billion, by 2050 there would still be 2200 dietary calories available per person per day, which is enough for us all to have adequate nutrition (Nb. the situation is the same if you examine calories, grams of protein, or grams of fats). In addition, at least 10% of global corn production that could be used for human consumption is used for bioenergy production (Graham-Rowe, 2011) and approximately 1/3 of the food currently produced globally is wasted before it is consumed (FAO, 2011). Overall, therefore, global data suggest that distributional problems are significant and these will not be rectified by simply increasing production. Finally, critics sometimes argue that the development of agricultural technologies, such as high-yielding seed varieties or other agri-inputs, typically benefit a small number of rich corporations and provide little in the way of meaningful progress towards reducing food insecurity (Tomlinson, 2013).

In light of these conflicting accounts and data, the purpose of this viewpoint article is to review the academic literature on topics relating to "solutions to the global food crisis". This is important because food scientists often find themselves inadvertently thrust into the heart of this acrimonious and volatile debate. For instance, in 2012 the UK government approved genetically modified (GM) wheat trials at Rothamsted Research. The scientists explained that their work is important for improving the sustainability of the food system: "Growing wheat has an environmental toll of extensive insecticide use to control aphid pests. The research, which is non-commercial, is investigating how to reduce that by getting the plants to repel aphids with a natural pheromone." (See more at: (Sense about Science, 2012)). But protestors disagreed, and one group called "Take Back Our Flour" wrote a series of letters to the *Guardian* newspaper where they declared that even doing research on GM may harm the integrity and sustainability of our food:

> Our vision is for an agro-ecology based farming involving using appropriate technology available to even the poorest farmers … [For] a food system that is not contaminated by GM or pesticides …. Empirical evidence shows that GM crops simply cannot co-exist with non-GM crops, so the choices we are making now have vital implications for future generations (Manchester Guardian, 2012).

Arguments over the most sustainable ways of feeding the world's population are not limited to disputes between environmental activists and bioengineers (Tscharntke et al. 2012). For instance, Badgley and Perfecto's (2007) article "Can organic agriculture feed the world?" concluded small farms that use crop rotation and avoid chemical inputs have the potential to address global food needs (See also: Badgley et al. 2007). Their article provoked a swift counter argument from Connor (2008) in a paper entitled: "Organic Agriculture Cannot Feed the World." Similarly, Seufert et al.'s (2012) meta-analysis in *Nature* found yields on organic farms were lower than those on conventional systems. This paper also launched a series of debates – both in the academy, and on social media – on the food production models best suited to meet global food security needs while protecting ecosystem services (Montenegro, Carlisle, Shattuck, & Kremen, 2012).

These illustrative debates – just two of many controversies related to the global food supply (i.e. food cloning, rBST, farmed salmon …) – show how researchers sometimes find themselves at the centre of polarized arguments that become entrenched around very distinctive technological, social, and ideological perspectives. In the hopes that a better understanding of these debates may be useful to scientists working on related topics, the purpose of this viewpoint review is to summarize some of the most prevalent themes in the food security literature. We aim to review the arguments for and against each position, and in doing so help food scientists understand some of the larger context of their research.[1]

2. Overview of key themes in the food security literature

Our reading of the literature suggests that there are at least four key pathways presented by scholars to solve "the global food crisis". These are:

1. Technology for Production. Arguments made under this theme stress the role of technological innovation to increase total production. Strategies proposed include using plant breeding and GM techniques to create disease or drought resistant varieties of plants, and bio-fortifying food crops.
2. Equity and Distribution. Arguments made in this theme stress the need for more equitable food distribution. Proposed strategies include poverty reduction, reducing global meat consumption, reducing the amount of grain used for bio-energy production, as well as changes to social welfare and trade regimes.
3. Local Food Sovereignty. Arguments made in this theme stress the need for communities to come together and promote more local and sovereign food systems. In wealthier countries these ideas are normally associated with "local food movements" while in the Global South – but increasingly in North America and Europe as well – these ideas are clustered around the notion of "food sovereignty".
4. Market Failures, Policy and Regulation. This theme stresses the need for policies and regulations to correct for perverse incentives that undermine the sustainability and security of our food systems. In particular, market failures and inappropriate subsidies result in pollution, waste, and excessive input, as well as leading to a proliferation of foods with large amounts of high-fructose corn syrup. Strategies proposed to correct market failures include incentives to reduce food waste, reducing distorting subsidies, and paying farmers for providing environmental benefits like carbon sequestration.

These themes are illustrated in Table 1 and the key arguments for/against each theme are summarized in the paragraphs below.

[1] *Methodological Note*. To explore debates on solutions to global food security, this viewpoint review article is based on the results of a systematic review of the scholarly literature. First, the research team created a database of scientific papers by querying the search engine "Web of Science" using the term "food security", restricting the range to articles published between 1993 and 2013. This generated 24,624 publications. The initial sample was narrowed down to only those articles that were published in highly cited international journals such as *Nature*, *Science*, *The Proceedings of the National Academy*, *The Philosophical Transactions of the Royal Society*, and subject-specific journals published by *Elsevier* and *Springer*. The research team systematically read through the sample, analysing the literature to identify recurrent themes until the point of theoretical saturation was reached. In this, we used an approach similar to that described by Braun and Clarke as a thematic content analysis (Braun & Clarke, 2006). Once we reached this point of theoretical saturation, eight senior scholars on the research team (two crop scientists, a food scientist, a global change modeller, a rural sociologist, and three human geographers who specialize on rural or food related topics) added supplementary readings and provided expert advice based on their disciplinary background. This led to a second round of critical reading where we reflected on, and confirmed the themes from, the first level of analysis. The critical reading process culminated in the development of a short (~1000 word) description of each theme, citing illustrative publications from the sample. These narratives were shared with the whole research team and edited in three rounds of revisions. The vast majority of the papers reviewed in this assessment were published between 1993 and 2013.

Table 1
Key themes, representative quotes, and key strategies that summarize current debates on global food security.

Theme	Representative quotes	Key strategies and illustrative references
Technology for Production	• "Low yields occur because of technical constraints that prevent local food producers from increasing productivity, or for economic reasons arising from market conditions." (Godfray et al. 2010b) • "To survive the droughts, wars and other major causes of famine, Africa must embrace technologies that enable it to produce more, better food with less effort." (Juma, 2011)	• Conventional plant breeding to develop F_1 hybrid varieties and disease-resistant varieties (Godfray et al. 2010a) • Genetic modification of crops for pest resistance or bio-fortification (Tester & Langridge, 2010) • Reduce political and cultural barriers preventing widespread adoption of molecular crop improvement (Fedoroff, 2013) • Market-led investment in agriculture (Parfitt et al., 2010)
Equity and Distribution	• "But availability does not assure access, and enough calories do not assure a healthy and nutritional diet. The distribution of the available food is critical." (Pinstrup-Andersen, 2009) • "If one person in eight starves regularly in the world, this is seen as the result of his inability to establish entitlement to enough food; the question of the physical availability of the food is not directly involved" (Sen, 1981)	• Reducing the consumption of meat (Godfray et al. 2010a) • Reducing the use of food crops for non-edible purposes (Thompson, 2012) • Improving of global distribution infrastructure (Lappé, 1971; Lappé, 2012) • Creating government food reserves (Devereux, 2002)
Local Food Sovereignty	• "Localizing and re-localizing food systems do not readily create enormous progressive societal changes. However, they do represent modest socio-economic, cultural and environmental shifts in encouraging directions." (Hinrichs, 2003) • "Food sovereignty movements politicize the current trade regime, revealing the complicity of states in incorporating agriculture into the reproduction of capital, rather than sustaining it as a site of social and ecological reproduction." (McMichael, 2009)	• Developing biologically diverse farms (Kloppenburg et al. 2007) • Empowering producers and consumers in local food systems (Patel & McMichael, 2009) • Reducing corporate control of the food system (Wittman, 2009)
Market Failure, Policy, and Regulation	• "While attempts to shift consumer behaviour may result in reduction in food waste in developed countries, changes in legislation and business behaviour towards more sustainable food production and consumption will be necessary to reduce waste from its current high levels." (Parfitt et al. 2010) • "In the meantime, a more fair and efficient use of these public resources would be achieved if policy sought more explicitly to internalize these external costs." (Pretty et al. 2000)	• Policies or technologies to reduce waste (FAO, 2011) • Policies to internalize externalized costs (Pretty et al. 2001) • Government measures for environmental protection (Pretty, 1999) • Policies to reward farmers for environmental goods and services (Redford & Adams, 2009) • Reducing energy and agrochemical inputs (Kloppenburg et al. 2007)

3. Pathway 1: technology for production

3.1. Summary of main arguments in support of the technology for production pathway

Arguments that support using technology to boost yields are typically predicated on global models that project rising demand for food due to population growth and rising affluence. The most commonly quoted statistic is that food production must double by 2050 to both address current food insecurity and meet this demand (Godfray et al. 2010a,b). Proponents of this pathway argue that biotechnologies, and in particular genetic engineering, are needed to create productive crops that are increasingly climate and pest resistant, to reduce pesticide use, and to improve the efficiency with which crops use nutrients and inputs. This narrative suggests that the regulatory burden placed on scientists (and companies) should be reduced in order to allow them to bring novel technologies, such as a new type of seed or input, to market faster (Edgerton, 2009; Fedoroff et al. 2010). Such advances would be critical in parts of the world where farmers only produce a fraction of their theoretical maximum, and scholars working on these topics often argue that closing these "yield gaps" represents an important scientific priority (Cassman et al. 2010; Foley et al. 2011; Jaggard et al. 2010; Juma, 2010; Peltonen-Sainio, Jauhiainen, & Laurila, 2009). For example, in many rice-growing regions, a lack of phosphorus limits yield. Farmers and scientists in India have long been aware that a traditional variety of rice called *Kasalath* is able to grow well in low phosphorus conditions due to the plant's ability to use phosphorus more efficiently than other varieties. In 2012, a group of scientists identified the gene responsible for this trait and are now working on using a mixture of biotechnologies and traditional plant breeding methods to develop locally adapted rice varieties with the enhanced ability to use phosphorus (Heuer et al. 2012). If developed, these new rice varieties have the potential to increase rice yields in parts of the world where access to phosphorus is limited. This pathway is summarized by Juma (2011) who writes: "to survive the droughts, wars and other major causes of famine, Africa must embrace technologies that enable it to produce more, better food with less effort."

3.2. Summary of main arguments challenging the technology for production pathway

Arguments that challenge the "technology for production" pathway fall into several broad categories. First is the "world already has enough food" argument, which cites global caloric production (in excess of 2850 dietary calories/person/day available in 2013 according to: FAO, 2015a,b) and analyses that suggest one third of the world's food is wasted before it is consumed (FAO, 2011). Also falling into this category are those authors who point out that about 40% of the corn in the USA is used for biofuel, while most of the remainder is used as animal feed and a source of high fructose corn syrup and corn oil, both of which are major inputs in fried and processed foods (Graham-Rowe, 2011). A second commonly expressed criticism of the technology for production theme is related to a perceived lack of equity in terms of ownership over agricultural biotechnologies (Tomlinson, 2013). Third, the most commonly used trans-genetic crops are herbicide-resistant corn, soy, and cotton, and varieties of corn and cotton that produce their own insecticide. The benefits of these crops are increasingly challenged by the emergence of insects and weeds that are tolerant to these pesticides (Powles, 2008; Shaner, 2000). For example, in parts of the USA, many weeds are becoming resistant to glyphosate, the main herbicide that GM crops can tolerate (Andrews, 2013; Benbrook, 2012). Similarly, the benefits of the *Bacillus thuringiensis* (Bt) crops, which were engineered to produce insecticidal toxins, have been reduced given the evolving resistance by the target pest corn rootworm (Gassmann et al. 2014). This highlights the fact that single gene traits are not robust long-term solutions to agronomic challenges as noted by Lee and Tollenaar (2007) and supports the idea that the benefits of technology (including GM technology) will be most fully realized in the context of (or when they aid in) the development and adoption of diverse and integrated farming systems (Russelle, Entz, & Franzluebbers, 2007).

Finally, many argue that "high-tech" crops, such as transgenic crops, will simply reinforce today's large-scale industrial food system that is already criticized for its impact on the environment (Feenstra, 2002; Weis, 2010), water quality (Xie, Xiong, Xing, Sun, & Zhu, 2007) and quantity (Hoeppner, Entz, McConkey, Zentner, & Nagy, 2006; Pimentel & Pimentel, 2008), animal welfare (Fraser, 2008), and its over-use of inputs such as energy and antibiotics (Silbergeld, Graham, & Price, 2008). Taken together, therefore, the critics of science and technology as the primary pathway to food security argue that technological solutions are likely to make the food system less sustainable, more energy intensive, and less equitable (Altieri & Rosset, 2002; Kimbrell, 2002; Patel, 2007; Sage, 2013; Shiva, 1993).

4. Pathway 2: Equity and distribution

4.1. Summary of main arguments in favour of the equity and distribution pathway

As already noted, many scholars have pointed out that food is unevenly distributed, and about 800 million people suffer chronic hunger while an additional 1.3 billion individuals are overweight/obese (Pinstrup-Andersen, 2009; Popkin, Adair, & Ng, 2012). Compounding the issue is the use of food crops for uses that are questionable in terms of nutrition (e.g. production of excessive sugars and fats) and crops grown for non-edible uses, highlighted by the US bioethanol industry that uses about 40% of the US maize harvests and has created a situation where grain that could be used to combat hunger is instead used for fuel (Searchinger et al. 2008; Tenenbaum, 2008; Thompson, 2012; Zhang, Lohr, Escalante, & Wetzstein, 2010). Hence, many argue that food security has less to do with the earth's capacity to produce calories than the ability of those most in need to obtain these calories (Elobeid & Hart, 2007; Zhang et al. 2010). Arguments about distribution date back at least to the early 1980s when Amartya Sen published the groundbreaking *Poverty and Famines* (Sen, 1981). In this book, Sen argued that food insecurity and famine are not caused by a lack of food as much as by a lack of economic and political power that would allow impoverished citizens to demand food in a highly inequitable world market (see also: Davis, 2002). Sen's book set the stage for three decades of development work based on the "sustainable livelihoods approach" to reduce poverty and food insecurity (Bebbington, 1999; Chambers & Conway, 1992; Scoones, 1998). The sustainable livelihoods approach works to assess and enhance the types of assets (both individual and communal) poor families can access in times of need (Morse & McNamara, 2013). Proponents of a livelihoods approach to food security suggest that poverty reduction, income redistribution, gender equality, and education (and specifically educational programs focused on girls) are all more effective measures to address food security than research to improve the productivity of seeds or the efficiency of farms (Fraser, 2007; Fraser, Simelton, Termansen, Gosling, & South, 2012; Nally, 2010; Simelton, Fraser, Termansen, Forster, & Dougill, 2009; Simelton et al. 2012). While reducing poverty and improving gender equality may indirectly stimulate food redistribution, others advocate for more specific strategies to ensure more equitable distribution. In particular, there are at least three broad strategies that are often discussed: First, we can reduce the use of edible grains for bio-ethanol. Second, we have the option of increasing direct distribution through food aid. Third, a shift in diet towards more plant based nutrition will free up land currently devoted to animal agriculture that could be used for human consumption. Each of these topics is discussed below.

4.2. Summary of main arguments challenging the equity and distribution pathway

One often-described way of improving food distribution is to reduce the amount of grains that are used for bioenergy production. In the media, this issue is sometimes referred to as the "food versus fuel" debate and was highlighted in late 2012 when a number of US governors requested the Environmental Protection Agency waive the requirement to blend ethanol from corn with gasoline (EPA, 2012). The politicians argued that this would help bring food prices down, thus ensuring more of America's grain would be available for human consumption (Haugen, 2012). But, as pointed out by Graham-Rowe (2011), the role of bioenergy policy on food prices is extremely complex. In particular, Graham–Rowe shows:

(1) Food prices are driven by much more than just the bioenergy industry (this conclusion is supported by recent data in a FAO study that shows that oil prices are to blame for high food prices (see FAO, 2015a,b));
(2) Biofuels are increasingly using non-edible crops or wastes and second-generation biofuel shares went from 3% of total renewable fuels in 2010 to 13% in 2015 based on US production data (EPA, 2014) and are projected to exceed first-generation production by 2022 (Renewable Fuels Association, No date). Note: under certain market conditions biofuels may be still grown on land that could be used for edible crops (e.g. Sanscartier et al. 2014);
(3) Even if biofuels are based on corn, once the sugars are removed from the corn for ethanol, a range of protein-rich by-products remain to be used as animal feed. So it is not as if these grains, the majority of which would have been used for livestock feed anyway, have been taken out of the food system. In fact, the amount of US corn available for export and other uses has remained fairly constant even as biofuel production has increased (in NCGA report but based on USDA statistics see: NCGA, 2012; NCGA, 2013; USDA, 2015a), largely due to higher yields and more land under corn production (USDA, 2015b).

Such arguments, therefore, lead many to question whether a reduction in the USA's use of corn for bioenergy would ensure more food availability or better food distribution (Thompson, 2012).

Second, experts argue that since some parts of the world have too much food, while others have too little, food could be redistributed as food aid. Despite the intuitively appealing logic, the history of food aid, defined as food given as charitable donations between nations, suggests that strategies used to distribute food are fraught with challenges. In particular, the whole notion of food aid is now questioned as an effective long-term strategy to address hunger and deprivation (Singer, 1987). For instance, a range of scholars have shown that food aid can be disastrous for local markets and cause a drop in farm incomes in recipient regions (Awokuse, 2011; Maxwell & Singer, 1979; Schultz, 1960). As a consequence, most development agencies today have moved away from using food aid except as a tool in short-term humanitarian relief efforts (World Food Program, 2010).

Third, another proposed way of improving food distribution is if rich consumers eat less meat, or only ate meat that came from grass fed systems of animal husbandry thus freeing up the grain that currently feeds livestock for human consumption (Rimas & Fraser, 2008; Smil, 2013). This approach was popularized by the vegetarian cookbook *Diet for a Small Planet* (Lappé, 1971), which implicitly argues there would be enough food for all if only the rich consumed less meat and dairy. This position has been taken up by Foley et al. (2011) and Godfray et al. (2010a) both of whom argue that one solution for the global food crisis is to eat less meat, and in particular, meat that comes from resource intensive "factory" farms. A problem remains: meat and dairy consumption is rising quickly at the global scale (Weis, 2013) and few policies or strategies seem effective at altering this trend (De Bakker & Dagevos, 2012). Educating consumers about the dangers of diets high in saturated fats is one approach. However, the challenge of dietary reform is highlighted by Smil (2011) who writes, "Obviously, even relatively small reductions in average meat consumption would have notable effects … But in the absence of higher meat costs, or lower average incomes, this is not a popular course to follow …" (p. 13).

5. Pathway 3: local food sovereignty

5.1. Summary of main arguments in favour of the local food sovereignty pathway

A third theme in the global food security literature centres on the development of local and sovereign food systems involving alternative, diverse, local, and often organic farms (Blay-Palmer, 2011; Renting, Marsden, & Banks, 2003). In this literature, it is not so much the scale that makes local systems preferable, rather it is the content of the agenda within the local scale that drives sustainability or justice (Born & Purcell, 2006). A general conclusion presented by authors writing in this literature is that a community's health and long-term sustainability are enhanced through developing local food systems (Allen, FitzSimmons, Goodman, & Warner, 2003; Born & Purcell, 2006; Connelly, Markey, & Roseland, 2011; ; Feenstra, 2002; Hinrichs, 2003). This is accomplished by biologically diverse "alternative" farming systems that require low fossil energy and agrochemical inputs, and situations where the actors who produce, process, and consume food are linked through social ties in a specific locality (Feenstra, 1993; Kloppenburg, Lezberg, De Master, Stevenson, & Hendrickson, 2007). Such alternative food systems are argued to offer a greater degree of equity, democracy, and sovereignty for all members of the community, improve the economic viability of farmers, and help protect the environment (Blay-Palmer, 2008; Hinrichs, 2000; Martinez et al. 2010). Food sovereignty refers to a collection of ideas that centre around the notion that to be food secure, consumers and producers both need to have the political, economic, or social power to be able to shape the food system they depend on (Torrez, 2010; Wittman, 2009). Proponents of this approach argue that local and sovereign food systems help poor and economically marginalized producers and consumers assert some control over the food systems on which they depend (Altieri, 1999; Patel & McMichael, 2009). Hence, arguments for developing local food systems are often closely aligned with both the environmental movement and also the anti-globalization movement (Altieri & Rosset, 2002; Lang & Heasman, 2004). Today, this position is often articulated by those who promote the 100-mile diet (Smith & Mackinnon, 2007) and rural studies scholarship that focuses on the transnational peasant movement, *La Via Campesina* (Desmarais, 2002, 2012).

5.2. Summary of main arguments challenging the local food sovereignty pathway

Many question whether local and sovereign food systems, based on low-input agriculture, and close links between consumers and farmers, can provide a viable food security strategy for the future. In particular, criticisms centre on two key areas: yield and scale. With regards to yield, some research suggests that biologically diverse farms may not be able to produce enough food to ensure global food security. For instance, Green, Cornell, Scharlemann, and Balmford (2005), Benton, Dougill, Fraser, and Howlett (2011) and Seufert, Ramankutty, and Foley (2012) all argue that farms using "alternative" methods (such as biodynamic or organic) tend to have lower yields when compared to conventional farms, (for example a hectare of organic wheat has a lower yield than a similar hectare of conventional wheat). It is important to note, however, that estimates vary on how much lower "alternative" yields are and some argue that mixed farms are better for food security (KC et al., 2015) and offer more stable farm income (Abson, Fraser, & Benton, 2013) even if the yields of specific crops are lower. Finally, while Seufert's (2012) analysis suggests that organic fields are, on average, ~25% less productive than conventional ones, Seufert's work, as well as Ponisio et al. (2015)'s study, also show considerable variation, suggesting considerable scope for increasing yields on organic farms in some localities and for some kinds of foods. There is also huge regional variation and one of Benton et al.'s (2011) key conclusions is that in regions where the landscape is naturally heterogeneous and yields are low, there is ample scope for a range of so-called "alternative agricultural" approaches to result in major increases in crop productivity without environmental challenges. Similarly, Benton et al. (2011) conclude that there is enormous scope for "greening" conventional farming systems to ensure that conventional farmers reduce their environmental impact while maintaining high yields. Hence, Benton et al.'s paper confirms Pretty's survey of "sustainable" agriculture projects in Africa that show promise for boosting productivity while enhancing the environment (Pretty, 1999).

A second common criticism against the promoters of alternative food systems is that for as long as alternative food enterprises, such as community supported agriculture or farmers markets, remain small they are often laborious, inconvenient and require consumers invest considerable time and energy. For instance, CoDyre, Fraser, and Landman (2015) point out that unless urban gardeners are extremely skilled and dedicated, then urban gardening is an extremely inefficient way of obtaining food (CoDyre et al. 2015). By contrast, whenever "alternative food enterprises" grow in scale they end up taking on many of the traits of conventional systems. For instance, critics argue that both fair trade and organic certification programs have been "watered down" in their attempt to access mainstream markets and that large-scale organic and fair trade farms cause many of the same problems as conventional ones (Dolan, 2010; Edward & Tallontire, 2009; Jaffee & Howard, 2010; Tallontire, 2009). As a consequence, a growing body of literature is now tackling the issue of how alternative food enterprises may (or may not) be able to scale up without losing the intrinsic characteristics and intended benefits that defined them as alternative in the first place (Mount, 2012). At present, there does not seem to be a strong consensus emerging in the literature as to whether this is possible. Furthermore, this debate reveals serious tensions within the organic movement between those who are more closely aligned with ideals related to social justice, seem likely to be opposed to large-scale organic and focus on creating an alternative family-farm-centric food system. This approach contrasts with large-scale producers who benefit from how organic has been defined by the US Dept. of Agriculture that focuses narrowly on a small number of management practices and inputs. Many of the organic farmers who either explicitly or implicitly subscribe to the more philosophical approach to organic farming are deeply concerned with how large scale farming systems have been certified as organic (please see chapter nine in Fraser & Rimas, 2010).

6. Pathway 4: market failure, policy, and regulation

6.1. Summary of main arguments in favour of the market failure, policy, and regulation pathway

A fourth distinct theme present in the literature on the global food crisis deals with "negative externalities" in the food system that are not captured by market prices or are caused by perverse incentives such as inappropriate subsidies (Panayotou, 1993). For farming, negative externalities include polluting farming practices (Pretty et al. 2001) the high energy and carbon footprint of the food system (Garnett, 2011), food poisoning (Pretty et al. 2000), food waste (Parfitt, Barthel, & Macnaughton, 2010; FAO, 2011; Kummu et al. 2012), obesity (Popkin et al. 2012), and global warming from fossil fuel use (Connelly et al. 2011; Smil, 2001). For instance, Pretty et al. (2000) attempted to calculate the "total cost" of UK agriculture, concluding that drinking water contamination, damaged habitat, soil erosion, and food poisoning imposed £2343 million of hidden costs on UK society in 1996. This pathway suggests that if consumers were obliged to pay the full cost of producing food, our systems would adjust and become more ecologically efficient (Benton et al. 2011; Connor & Mínguez, 2012; Tscharntke et al. 2012). Similarly, corn subsidies that reduce the cost of processed food high in sugar represents a policy where the health consequences of our diets are not reflected in the price consumers pay. In this literature, these ideas are sometimes linked with the notion of "ecological intensification", which is defined as the "… maximization of primary production per unit area without compromising the ability of the system to sustain its productive capacity"(Cassman, 1999; Firbank, 2005; Food and Agricultural Organisation, 2009; Green et al. 2005; Rudel et al. 2009; See also: Benton et al. 2011; Connor & Mínguez, 2012). Policies to address this include pollution taxes and payment for ecosystem services, each of which try to create financial incentives to reduce the impact of farming on the environment. Similar policies are used to address social market failures as well.

6.2. Summary of main arguments challenging the policy and regulation pathway

Many scholars criticize the notion that it is possible to establish regulatory frameworks to reduce the negative externalities in our current system. Some authors argue that regulations rarely make farming more ecologically efficient and usually only serve to stifle innovation (Burton, Kuczera, & Schwarz, 2008; Tamilia & Charlebois, 2007). Hence, a large body of literature questions whether environmental legislation does anything more than increase the costs associated with producing food, thus penalizing innovative farmers (Fedoroff et al. 2010; Miller & Conko, 2000; Wu, 2006). For instance, in a widely cited study on the effectiveness of EU schemes designed to promote biodiversity conservation in agricultural landscapes, Kleijn and Sutherland (2003) conclude that despite having spent 25.3 billion Euros on agri-environmental schemes up to 2003, it was impossible to ascertain whether these policies had any measurable effect on improving biodiversity. A follow-up study from 2006 was only slightly more positive and showed that these schemes had "marginal" and "moderately positive" effects (Kleijn et al. 2006). In terms of policies to reduce food waste, the research is somewhat more positive. It has been suggested that innovative technology, particularly in packaging, which extends the shelf life of perishable foods and semi-prepared meals, could potentially reduce food waste in developed countries (Parfitt et al. 2010). In developing and emerging economies, "market-led large-scale investment in agricultural infrastructure, technological skills and knowledge, storage, transport and distribution" hold great potential for waste reduction (Parfitt et al. 2010). But even here the debate surrounding the need to internalize the full costs of the food system exposes ironies and tensions. If an underlying cause of food waste in the developed world is that food is so inexpensive that it is easily wasted, then a proposed solution must be to enact policies to make the consumer bear the full cost of food production and distribution. But while such policies should make food too valuable to waste, these same policies could lead to worse food insecurity and malnutrition in poorer communities.

7. Discussion

We would like to conclude this viewpoint article by picking up on three key points.

- First, in our observation, each of the four pathways described above has a particular set of stakeholders behind it that represent different constituents, each of which has different expectations and demands. In the past, because proponents of each paradigm came from different positions, debates about the most appropriate solutions to food security have resulted in acrimony and, in many cases, a policy stalemate (see below).
- Second, it is our view that no single solution will work in every instance and so food security experts need to be looking to develop a "blended portfolio" of strategies rather than maintaining their allegiance to only one type of strategy.
- Finally, developing inclusive and participatory decision making processes to decide on specific policies, technologies or management practices may be more important than focussing narrowly on any specific tool (such as biotechnology or local food systems).

With regard to the first of these three points, it is clear from the literature that debates between proponents of the four pathways identified above have, in the past, resulted in what can only be described as a "policy stalemate". For instance, the introduction of this paper alluded to acrimonious debates between environmental activists and food scientists working on GM crops. Perhaps the most extreme example of how arguments over food security can derail policy-making occurred during the writing of the global report for *The International Assessment of Agricultural Knowledge, Science and Technology for Development* (IAASTD). IAASTD was convened by the United Nations following the Johannesburg Summit on Sustainable Development in 2002. It was designed to act in a similar capacity as The Intergovernmental Panel on Climate Change (IPCC) in that it was to establish a multi-stakeholder group of experts who would assess and review the state of scientific knowledge pertaining to agriculture and food security. According to Edwards (2012) despite the fact that IAASTD was launched with high-level political support and an impressive array of scientific contributors, "almost everything that could go wrong did" (p. 70). Edwards describes the situation:

> Civil society representatives clashed with agronomists over the value of physical science vs. traditional knowledge. Business delegates clashed with civil society representatives over the merits of large-scale agribusiness vs. small-scale village farming systems. State delegates and civil society representatives clashed over who could legitimately speak for peasant farmers: their governments or international NGOs working directly with farmers. (p. 75)

In the end, the only real point of agreement was to terminate IAASTD after the first synthesis report was published. But even this report was rejected by the governments of Canada, the US, and

Australia. At least two academic papers have been published on the IAASTD. In one, Edwards (2012) concludes that it was disagreements between proponents of local food sovereignty and proponents of technology that caused this rift; similar conclusions are reached by Scoones (2009). In particular, Edwards argues that there were serious epistemological differences between these camps that became politicized and entrenched. As a result, meetings of contributing scholars that were supposed to discuss data and science dissolved into arguments over the role of agribusiness, globalization, traditional versus scientific knowledge, and whether biotechnology can play a meaningful role in promoting food security. Therefore, both Edwards and Scoones treat the failure of the IAASTD process as a cautionary tale that illustrates how debates over global food security can derail well-meaning policy and scientific discussions. Incidentally, Hulme highlights similar tensions in his study over why people disagree over climate change. In particular, Hulme concludes that it is critical to explore the discordant voices and multifarious knowledge claims in order to help identify the ideas different people in diverse places and times have about the issue at stake (Hulme, 2008, 2009).

Building on this lesson, one of the key conclusions that the authors of this viewpoint paper would like to make is that no single pathway will work in every situation. There are many situations when the unthinking promotion of a specific tool ended up undermining food security. For instance, Scott's (1985) study shows how Western development experts tried to reduce food insecurity in Asia by promoting labour-saving tools such as rice combine harvesters. All this equipment did was increase rural unemployment and consequently the tool was unsuited to the local environment and rejected by the people who were supposed to benefit from it. Therefore, what is needed is a sort of "blended portfolio" of food security strategies where the strengths and weaknesses of different approaches are balanced. Furthermore, such an approach could be explicitly based on core objectives such as equity, sustainability and nutrition.

But while promoting such a blended portfolio of food security strategies is a nice theoretical aspiration, the critical question remains: what guidance is there to allow policy makers, scientists, farmers or business leaders to actually achieve this goal? To answer this question, we would like to turn to the literature that pertains to participatory environmental management. Briefly, a key insight from this body of work is that decision making can be improved if scientists and policy makers (so-called "experts") work in greater partnership with farmers, concerned citizens, and other "non-experts." This requires that less powerful stakeholders gain access to resources (such as access to legal advice or technical expertise) and the goal is to ensure that there is a clear, fair and transparent process to identify problems, decide on locally relevant solutions, and develop accountable evaluation frameworks to ascertain whether or not strategies have been effective (e.g. see: Dougill et al. 2006; Fraser, Dougill, Mabee, Reed, & McAlpine, 2006; Reed, Fraser, & Dougill, 2006; Stringer et al. 2006).

One of the most high-profile examples of this sort of process is the World Commission on Dams that established a multi-stakeholder and participatory process for planning, implementing and decommissioning large-scale water and energy projects (World Commission on Dams, 2010a). The World Commission on Dams posits that decision-making must be underpinned by the need for demonstrated multi-stakeholder acceptance, as well as free, prior and informed consent (World Commission on Dams, 2010b). While the World Commission on Dams provides us with a starting point in thinking about how to conduct a participatory process, problems remain. For instance, when compared with agriculture and development projects, it is relatively easy to identify relevant stakeholders in large-scale hydro-electric projects, so we acknowledge that capturing an appropriate social network with whom to engage with is extremely challenging. One way of overcoming such hurdles is to use an approach called "mediated modelling" that provides a structure to identify relevant stakeholders (Reed et al. 2006) and can be used to help scientists and other stakeholders build a shared understanding of the drivers of food security (or other topics) in a region. Mediated modelling, which starts by mapping the relevant social network and then provides tools to help identify drivers, feedbacks and intervention points represents one way of bringing different perspectives together to explore how proposed strategies may cause unintended consequences. Dougill, Fraser, and Reed (2010), for instance, applied this process to identify how different policies changed livelihood and food security strategies in Botswana (see also Fraser et al., 2011 for an introduction to a special issue of the journal *Ecology and Society* on this topic and Dougill et al. 2006 for an application of this approach to land management in rural UK). While mediated modelling provides one process-based tool that tries to combine the benefits of "bottom-up" participation and "top down" expert advice (Fraser et al. 2006), our core message is that developing such a deliberative process is crucial to developing solutions to the global food crisis.

8. Conclusion

When considering food security, policy makers, scientists, and activists must carefully consider each of the four pathways outlined in this paper. To do so, however, requires a large degree of collective coordination at local through to international scales. A major concern is that today the intellectual debate on food security risks descending into a policy stalemate – with the hungry paying the highest cost. Therefore, the authors of this paper hope that this viewpoint article provides some clarification of these issues and, along with our attempt to highlight the key points of convergence and contestation, we hope to have provided a helpful distillation of core tenets surrounding the challenges and solutions to solving the global food crisis.

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