UTILIZING ENERGY INFRASTRUCTURE IN THE FIGHT AGAINST FOOD INSECURITY

Abstract

Food insecurity is generally defined as a state of inadequate or inconsistent access to food. It impacts nearly 10% of the global population and particularly stymies growth in developing countries. Food insecurity can be caused by a number of issues, including production shortages, spoilage, poor food distribution, and insufficient infrastructure to support food vending. Whatever the cause, food insecurity has crippling impacts. A lack of food precludes a person from developing physically and mentally, negatively impacts health, limits productivity, and generally worsens quality of life.[1]

Food insecurity is exacerbated by a lack of access to reliable energy – commonly referred to as "energy poverty" – that acts as an insurmountable barrier to producing and obtaining nutritious food. Energy is often a pre-requisite to food circulation and is necessary to power mechanized farm equipment, logistical systems for food distribution, and apparatuses that safely cook food. Figure 1 and Figure 2 below show this overlap on a global scale.

The maps show that generally, the regions that suffer most from energy poverty are also the regions that suffer most from food insecurity. Yet, this relationship has received insufficient attention from scholars, policymakers, and citizens alike, as there are few, if any, large scale, publicized efforts to date that jointly address energy poverty and food insecurity Ironically, as new agricultural technologies are touted as silver bullets to address world hunger, few people are acknowledging the predicate need for energy to power those technologies.

[1] The World Technology Network, "Repercussions: What are the effects of Hunger?," *The World Technology Network*, 2013, Accessed August 12, 2016, https://www.wtn.net/hungerinitiative/Repercussions.php.

Figure 1. Percentage of Citizens with Access to Electricity[2]

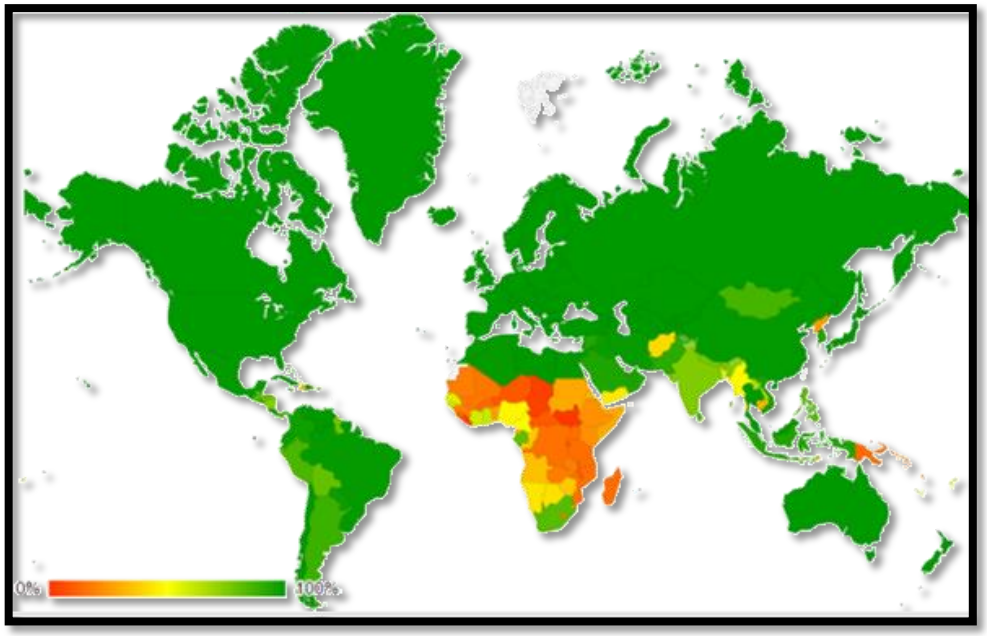
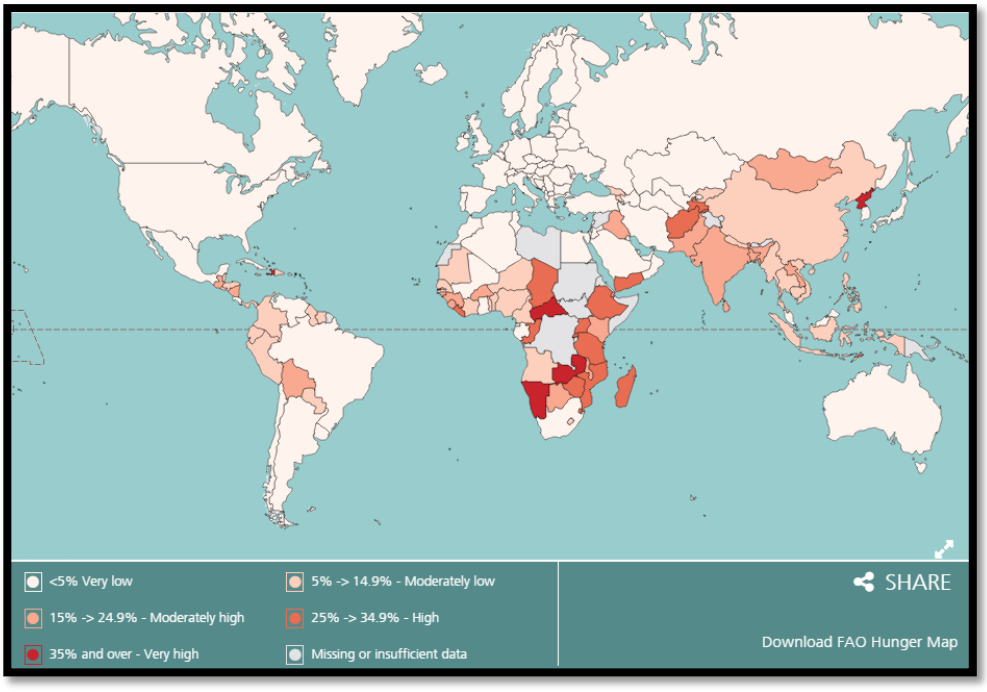


Figure 2. Percentage of Citizens Suffering from Undernourishment[3]



[2] Jordan Hanania, Kailyn Stenhouse, and Jason Donev, "Access to Electricity," *University of Calgary*, Accessed August 12, 2016, http://energyeducation.ca/encyclopedia/Access_to_electricity.
[3] Food and Agriculture Organization of the United Nations, "The FAO Hunger Map 2015," *The United Nations*, 2015, Accessed August 12, 2016, http://www.fao.org/hunger/en/.

Introduction

Every four seconds, a life is cut short by hunger or a related cause. Over the course of just one short month, this total amounts to the population of Washington, DC.[4] The United States Department of Agriculture, consistent with the generally accepted definition, defines food insecurity as a situation in which "...access to adequate food is limited by a lack of money and other resources."[5] These resources mainly include food storage equipment, food distribution outlets, access to food markets, and access to healthy food. Due to a lack of one or more resources, the Food and Agriculture Organization of the United Nations (FAO) reports that 795 million people are undernourished across the world; 780 million of those people live in developing countries and in total, one in nine people goes to bed hungry on a nightly basis.[6] Although this data suggests an improvement from prior years, it still falls below the 2000 UN Millennium Summit goal of reducing the proportion of people suffering from hunger by half by 2015. The figure also falls well below the goal set by the 1996 World Food Summit. The summit, a reflection of 182 different governments, aimed to halve the number of undernourished people by the year 2015. Causes of these failures are threefold: economic factors, sociopolitical factors, and environmental impacts.[7] Environmental impacts are among the most unpredictable, primarily manifesting in severe weather and natural disasters. Both of these seriously destroy crops and agricultural supplies, creating food shortages at the source.[8] Additionally, weather can demolish infrastructure, such as roads, that are crucial for distributing food, further decreasing

[4] "Hunger and World Poverty," *Poverty.com,* Accessed August 12, 2016, http://www.poverty.com/.
[5] Andrews, Margaret, Steven Carlson, Alisha Coleman-Jensen, and Mark Nord. *Household Food Security in the United States in 2011,* U.S. Department of Agriculture, Economic Research Service, 2012. Accessed June 9, 2016. http://www.ers.usda.gov/media/884529/err-141-summary.pdf
[6] Stop Hunger Now, "Hunger Facts and Quotes," *Stop Hunger Now*, Accessed August 12, 2016, http://www.stophungernow.org/learn/hunger-facts/.
[7] Food and Agriculture Organization of the United Nations. *The State of Food Insecurity in the World.* Rome: FAO, 2015. Accessed June 9, 2016. http://www.fao.org/3/a-i4646e.pdf
[8] Child Fund International, "The Devastating Impact of Natural Disasters," *Child Fund International*, February 6, 2013, Accessed August 12, 2016, https://www.childfund.org/Content/NewsDetail/2147489272/.

food availability. Some studies have found that the weather patterns resulting from climate change in particular could wind up being responsible for a 17% decrease, on average, in global crop yields in 2050.[9] Economic price shocks, which can occur due to supply changes, tariffs, and other stimuli, tend to harm those closest to starvation. Families in the poorest income brackets in developing countries often spend between 60-80% of their income on food. As a result, when food prices rise or when their incomes fall, these people are often unable to increase spending to maintain their previous levels of food consumption.[10] Social conditions, namely political instability and conflict, also dictate levels of food insecurity. Conflict or lack of political safety can make acquiring food dangerous if a region is rife with violence. Also, without an effective government, importing food and regulating agricultural commerce can be challenging. Indeed, an FAO study found that in areas of conflict, the number of deaths resulting from food insecurity can outnumber the deaths due to the conflict itself.[11] In simple terms, the issue of food insecurity is overwhelmingly prevalent and efforts to mitigate it must significantly improve.

In general, these economic, sociopolitical, and environmental factors influence food circulation by showing up in at least one of four food circulation stages: food production, food refinement, food transportation, and food storage (figure 3 briefly describes each stage's role in circulating food to consumers in order to facilitate understanding of the following sections). At each stage, unique challenges exist that threaten our ability to sustain global food demand and to effectively alleviate food insecurity. It is imperative to address all factors at all stages of the food circulation process.

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[9] Gerald C. Nelson et al., "Climate change effects on agriculture: Economic responses to biophysical shocks," *Proceedings of the National Academy of Sciences of the United States* 111, no. 9 (2013): 10.1073.

[10] The World Food Programme, "How High Food Prices Affect The World's Poor," *The World Food Programme*, September 4, 2012, Accessed August 12, 2016, https://www.wfp.org/stories/how-high-food-prices-affect-worlds-poor.

[11] Simmons, Emmy. *Harvesting Peace: Food Security, Conflict, and Cooperation*. Washington, DC: Woodrow Wilson International Center for Scholars, 2013. Accessed August 12, 2016. https://www.wilsoncenter.org/sites/default/files/HarvestingPeace.pdf.

Figure 3. The Stages of Food Circulation[12]

Food Production
Food Production includes the planting and harvest of food along with maintenance of crops during growing seasons; this phase ends after harvest.

Food Refinement
Food Refinement includes the maintenance of health, safety, and nutritional value of food; this phase begins after harvest and ends only after consumption.

Food Storage
Food Storage includes any retention of food at any point during food circulation; this phase ends after consumption.

Food Transportation
Food Transportation includes any shipment of food from one location to the another; this phase can be broken into several segments and ends when the product reaches its final location (the consumer).

CONSUMPTION

[12] Images are copyrighted (compiled from Google Images)

The Role of Energy as a Prerequisite to Food Insecurity

Each stage of food circulation relies heavily on energy. Food production requires energy to pump water and power machines; food refinement uses energy to heat and clean food; food distribution is dependent on energy to sustain vehicles and communications systems; food storage requires energy to maintain optimal environments in which food can be stored. In total, the food circulation process uses 30% of the world's available energy and produces 20% of the world's greenhouse gas emissions.[13] Many argue that small family farms, which account for 90% of the world's farms, can function without relying on energy at any point in the food circulation process.[14] This is quickly refuted by an FAO platform, which specifically cites a lack of technology and a lack of electricity as common challenges that family farmers face.[15] Thus, it follows intuitively that if energy poor areas are electrified, those places can engage in food circulation with greater effectiveness and ease. Even where infrastructure exists, bolstering existing energy systems can lead to increased efficiency and fewer unintended social costs in all stages of the food circulation process. For example, equipping a rural village with clean energy would allow villagers to cook nutritious food without inhaling fumes from charcoal ovens. Providing farmers with sustainable energy to collect water for their crops would allow them to consistently water their fields and produce strong yields, boosting average production. Whatever the case, energy can, and should, play a lead role in combatting food insecurity throughout the world.

[13] Food and Agriculture Organization of the United Nations. *Energy-Smart Food at FAO: An Overview*. Rome: FAO, 2014.
[14] Food and Agriculture Organization of the United Nations, "Smallholder family farms," *FAO,* Accessed August 12, 2016, http://www.fao.org/economic/esa/esa-activities/esa-smallholders/smallholders/en/.
[15] Food and Agriculture Organization of the United Nations, "FAO launches digital platform on family farming," *FAO,* Accessed August 12, 2016, http://www.fao.org/news/story/en/item/293696/icode/.

The following subsections will outline in greater detail what the current role of energy is in each stage of the food circulation process and how its role can be adjusted to mitigate the impacts of Food Insecurity.

Food Production

Food production encompasses everything from planting the seeds to harvesting the crops; it is responsible for creating the supply of food that ultimately enters the agricultural market. Tasks that fall under food production include tilling land, watering crops, fertilizing farmland, and anything else required to produce a healthy product. Due to the world's unwavering demand for food, the agricultural industry is considered "supply driven."[16] This designation is critical, as it reveals the importance of food production to food security. The price and availability of food rely on the success of food producers. A fruitful harvest will ensure an ample supply of food for consumers; but, a lackluster harvest can result in food shortages – which subsequently restrict access to food. These shortages are unlikely to be rectified. Thus, in order to ensure an adequate global food supply, food production must maintain a high degree of reliability. Food production is increasing annually by just enough to satisfy population growth and associated increases in food demand. GRID-Arendal and the United Nations Environmental Programme, working in conjunction on environmental capacity analyses, note that global food production has increased as a result of increased yield per unit area (the largest causal factor), increased cropland, and increased frequency of plantings. Still, both organizations acknowledge that the aggregate number of undernourished people has increased and that the addition of three billion more people

[16] Hueston, Will. *Overview of Global Food System: Changes over Time/Space and Lessons for the Future*. University of Minnesota. Accessed August 12, 2016. http://www.nationalacademies.org/hmd/~/media/3E4C4C44EB194E8DAD2D66F9314B3A1F.ashx.

to the global population by 2050 will strain food demand.[17] While GRID-A and UNEP are somewhat optimistic, researchers at the University of Minnesota paint a grimmer picture in a study published in *PLOS One*. Researchers examined projections for production growth of maize, rice, wheat, and soybean and found that the predicted increases in the yields of these crops will fall well below the expected rise in food demand for the year 2050. More broadly, these researchers conclude that without a steep improvement in production efficiency, food production will not be able to meet food demand in 2050.[18] Given the current rate of food production growth, optimistic estimates assert that satisfying food demand will soon be a close call and less optimistic estimates contend that satisfying food demand will soon be far out of reach. It should be noted that the aforementioned studies both assume that food distribution, food storage, and food refinement will remain unchanged. This is a significant assumption because if the three other aforementioned facets of food circulation do not remain the same and instead improve, the burden of progress on food production will fall and as a result, seemingly underwhelming increases in food production may in fact be enough to meet food demand. Regardless, improving food production can still help alleviate food insecurity by increasing the availability of food to consumers. Thus, the urgency with which improving food production is approached with must remain the same.

Augmenting food production faces many key challenges. Economically, rising production costs and lowering profit margins due to international competition makes agricultural work less economically attractive and viable. Environmentally, increasing output while maintaining arable qualities of land is difficult; also, natural disasters and increasingly

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[17] Nellemann, Christian, M. MacDevette, T. Manders, B. Eickhout, B. Svihus, A.G. Prins, and B.P. Kaltenborn. *The Environmental Food Crisis: The Environment's Role in Averting Future Food Crises*. United Nations Environmental Programme, 2009. Accessed June 10, 2016. http://www.grida.no/files/publications/FoodCrisis_lores.pdf

[18] Ray, Deepak K., Nathaniel D. Mueller, Paul C. West, and Jonathan A. Foley. "Yield Trends Are Insufficient to Double Global Crop Production by 2050." *PLOS ONE* 8(6), no. e66428 (2013). doi: 10.1371/journal.pone.0066428.

unpredictable weather patterns have reduced the reliability of advanced scheduling in harvesting. Politically, rules and regulations, while helpful for general welfare in many cases, create additional hurdles for producers. These and several other challenges necessitate a new advent to facilitate increases in food production across the world.

The Role of Energy in Food Production

The Status Quo

In order to understand how intertwined energy and food production are, consider the following hypothetical process of producing salad:

> In this case, fresh vegetable farms in California harvest the produce to be used in the salad mix a few weeks prior to its purchase. The farms' fields are seeded months earlier with a precision seed planter operating as an attachment to a gasoline-powered farm tractor. Between planting and harvest, a diesel-powered broadcast spreader applies nitrogen-based fertilizers, pesticides, and herbicides, all manufactured using differing amounts of natural gas and electricity and shipped in diesel-powered trucks to a nearby farm supply wholesaler. Local farmers travel to the wholesaler in gasoline-powered vehicles to purchase farm supplies. The farms use electric-powered irrigation equipment throughout much of the growing period. At harvest, field workers pack harvested vegetables in boxes produced at a paper mill and load them in gasoline-powered trucks for shipment to a regional processing plant, where specialized machinery cleans, cuts, mixes, and packages the salad mixes.[19]

In this single example, it is clear that energy is critical to several key stages of the food production process, without even factoring in the machinery used to harvest and clean crops, or the technology necessary to coordinate the logistics of harvesting in large farms.

In addition to the actual harvesting, energy in food production is critical for fertilizer/pesticide use, tilling, and irrigation, among other necessary functions. The amount of energy for each job varies by crop, but generally the harvest, fertilization, and irrigation require the most energy (around 90%) while tilling and other miscellaneous jobs consume just around 2% of total energy used. Overall, natural gas and petroleum make up the overwhelming majority

[19] Canning, Patrick, Ainsley Charles, Sonya Huang, Karen R. Polenske, and Arnold Waters. *Energy Use in the U.S. Food System*. Washington, DC: US Department of Agriculture, 2010.

of energy use in food production, with electricity following and coal lagging much further behind.[20] It should be clarified that energy used in energy production includes energy used in the production of fertilizers and pesticides, which involves various fuels and chemicals including natural gas (used to produce the ammonia component).

An implementation or upgrade of any energy system would benefit a region struggling with systematic food production as energy can rejuvenate otherwise middling results. However, different forms of energy come with different benefit packages and varying associated costs. "Dirty" energy sources (coal, oil, etc.) harm the environment and are often tied to volatile markets, making their financial costs unpredictable.[21] Additionally, these energy sources are also intensive to cultivate, requiring mines, rigs, long range transportation infrastructure, and other large assets. So, while these sources of energy can produce power fairly consistently, users must be willing to incur significant start-up and maintenance costs along with heavy environmental damages. Natural gas advocates claim that this form of non-renewable energy is less prone to the aforementioned disadvantages of dirty energy sources. But, while natural gas burns cleaner than coal, retrieving it requires one of the most expansive sets of infrastructure – often outside the budget of poor regions in need of energy – and still carries environmental costs.[22] Sustainable energy sources serve as solutions to environmental problems and to the uncertainty of volatile commodities markets by relying on free and environmentally friendly resources (e.g. wind, the sun). Additionally, sustainable energy sources, particularly solar energy, have been the center of successful energy projects in developing regions that collectively clamor for energy. So long as

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[20] Jennifer Burney, "How much energy does your meal require?" (presentation, Program on Food Security & the Environment, Stanford Scripps Institution of Oceanography, University of California, San Diego).
[21] Society for Mining, Metallurgy, and Exploration, "Coal's Importance in the US and Global Energy Supply," *Society for Mining, Metallurgy, and Exploration,* Accessed August 12, 2016, http://www.smenet.org/about-sme/government-affairs/advocacy/technical-briefing-papers/coal-s-importance-in-the-us-and-global-energy-supp.
[22] National Latino Council on Alcohol and Tobacco Prevention, "7 Key Pros And Cons Of Natural Gas," *NLCATP,* December 27, 2014, Accessed August 12, 2016, http://nlcatp.org/7-key-pros-and-cons-of-natural-gas/.

technologies are properly utilized, sustainable energies have the capacities to power entire villages without the slew of costs that come with other energy systems.[23] Therefore, while adding just about any source of energy is to the farming process is preferable to an energy-less agricultural process, sustainable energy ought to be prioritized in order to maximize benefits.

Integrating Energy

There are two different methods of integrating energy into agricultural production: introducing energy and enhancing energy. Energy introduction applies to agricultural systems that are completely manual while energy enhancement pertains to systems where energy exists, but can be greatly improved.

Energy introduction has been effective throughout the world. A comprehensive study examining 14 countries in and around Sub-Saharan Africa perhaps unsurprisingly found that the introduction of mechanized farm power increased labor efficiency, reduced production costs, increased the area cultivated, increased yields, allowed for the adoption of new crops, and reduced harvest and postharvest losses.[24] In Nepal, replacing cows with mechanized plowing devices cut crop loss by half and improved crop quality.[25] Similar results are seen in the Philippines, Vietnam, and essentially every developing country across the world. In many of these aforementioned cases, energy is introduced in the form of petroleum, diesel, and other non-renewable fuels using tractors and other farm vehicles as conduits. In addition, the introduction of electricity has the potential to modernize and improve energy-less farms. Electricity can power systems to irrigate crops quickly and evenly, protect crops from frost and general swings

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[23] Flowers, L., et al., *Renewables for Sustainable Village Power.* Golden: National Renewable Energy Lab, 2000. Accessed August 12, 2016. http://www.nrel.gov/docs/fy01osti/28595.pdf.
[24] Bishop-Sambrook, Clare. *Contribution of farm power to smallholder livelihoods in sub-Saharan Africa*. Rome: Food and Agriculture Organization of the United Nations, 2005.
[25] Rabatsky, Bob, "Restating the case for modernising smallholder farming,"*The Guardian, April 15,* 2013, Accessed June 24, 2016, http://www.theguardian.com/global-development-professionals-network/2013/apr/15/agriculture-technology-smallholder-farmers.

in temperatures, provide necessary conditions to raise livestock, fuel greenhouses, and power general farm equipment.[26] A case study in Brazil found that electrifying a farm improved crop productivity and total crop production without requiring more land. The study demonstrated that a 10% increase in access to electricity across Brazilian farms resulted in about a 20% increase in agricultural productivity and also implied that electrification of farms opened the door for more agricultural growth and development overall. Additionally, the study reported that electrification of farms caused a decrease in deforestation, producing a side benefit of environmental conservation.[27]

Farming systems that already utilize energy can still benefit from upgrades in their energy infrastructure. As demonstrated through the aforementioned Brazil case study, increases, not just introductions, of energy make crop production more effective. Thus, simply increasing the amount of energy available will allow for the completion of a higher number and a more complex set of tasks in less time. Additionally, switching to energy-efficient sources of energy can reduce the amount of energy expended during farming. For example, using LED lights or Compact Fluorescent Lights instead of incandescent lights, which are less energy-efficient, can lower long-term costs by sapping less energy. The same effect can be achieved by switching to more fuel efficient tractors and tilling vehicles. Building and relocating electric grids closer to farmland or using more conducive metals during energy transport would reduce energy lost during transmission. In addition, upgrading existing energy systems to sustainable energy systems, as alluded to previously, can reduce the economic risks and environmental impacts of agricultural production. Switching from coal or natural gas to solar or wind energy in generating

[26] Schnepf, Randy. *Energy Use in Agriculture: Background and Issues.* Congressional Research Service, 2004. Accessed August 12, 2016. http://nationalaglawcenter.org/wp-content/uploads/assets/crs/RL32677.pdf.
[27] Assunção, Juliano, et al., *Electrification, Agricultural Productivity and Deforestation in Brazil.* 2015. Accessed August 12, 2016. https://economics.stanford.edu/sites/default/files/mobarak.pdf.

electricity would reduce carbon and other greenhouse gas emissions. Utilizing these technologies would also establish independence of the farm from commodities markets. So, even farm systems that are already energized have great potential for improvement.

Food Refinement

Food refinement is the maintenance and retention of the inherent nutrition, sanitation, and health of foods. Maintaining the sanitation of food requires several safeguards. Temperature control, throughout food circulation, is important in order to prevent the development of pathogens in food. Bacteria, especially, are of high concern, given that they thrive in unfavorable conditions and multiply rapidly.[28] For example, E. Coli bacteria is capable of doubling every 20 minutes; other bacteria are capable of doubling in just four minutes.[29] Sanitation necessitates hygienic food handling practices. The assurance that food is not contaminated comes from proper heating and ventilation, drainage, lighting, waste management, water treatment, humidity control, and other safeguards.[30] Retention of nutrients in food is also vital to food refinement. Poor maintenance of crops combined with unchecked environmental factors such as extreme temperature and humidity can easily lead to depreciation in the nutritional qualities of food. For example, overheating food can remove water-soluble vitamins through steam and condensation. Improper handling of cereals can damage their husks, which contain important dosages of fiber. High exposure to nitrogen can drastically reduce Vitamin C levels in fruits and vegetables.[31]

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[28] Synergy Training Solutions, "ServSave Food Protection Manager Study Guide," *Hartnell College,* Accessed August 12, 2016, http://www.hartnell.edu/sites/default/files/u87/food_safety_guide.pdf.
[29] Pacific Northwest National Laboratory, "Just How Fast Can Bacteria Grow? It Depends," *US Department of Energy*, December 2010, Accessed August 12, 2016, http://www.pnnl.gov/science/highlights/highlight.asp?id=879&groupid=753.
[30] Schmidt, Ronald H. *Basic Elements of a Sanitation Program for Food Processing and Food Handling*. University of Florida. Accessed August 12, 2016. http://edis.ifas.ufl.edu/pdffiles/FS/FS07600.pdf.
[31] Victoria State Government, "Food Processing and Nutrition," *Victoria State Government*, 2016, Accessed August 12, 2016, https://www.betterhealth.vic.gov.au/health/healthyliving/food-processing-and-nutrition.

These examples illustrate the fact that food must be carefully tended to in order to ensure consumers are able to enjoy the full nutritional benefits of their food. Food insecurity is most often described by levels of undernourishment instead of levels of hunger. This is an especially critical distinction, as there is a difference between simply feeding the hungry versus properly nourishing these communities Food with insufficient nutrients will solve hunger, but will not solve undernourishment. The World Health Organization reports that over 200 diseases can be commonly carried in improperly refined foods. These diseases impact millions of people annually, particularly those who are already medically vulnerable, including young children and the elderly. The WHO also warns that with more globalization, supply chains get longer and there are more opportunities for the contamination of food.[32] Food quality can deteriorate as an immediate result of improper harvesting, insufficient examination after harvest, poor transportation and storage, or as a result of a multitude of other impacts that occur all throughout the food circulation process. Thus, it is vital that the global community acts to improve food refinement methods to ensure not only that food reaches those in need, but also that food *safely* reaches those in need.

The challenges in ensuring food safety have been becoming increasingly complex in recent years, as if to keep pace with technological growth. The World Health Organization lists several emerging factors that may derail efforts to make food safer. Among these are climate change, expansion of food supply chains, and the diminishing effectiveness of antibacterial and related substances. Climate change, and the weather changes that result from it, oftentimes cause unpredictable variations in the timetables for when crops are fresh and when crops have gone bad; as these variations increase in unpredictability, maintaining freshness and optimal health of

[32] World Health Organization, "10 Facts on Food Safety," *World Health Organization*, February 2015 Accessed June 6, 2016, http://www.who.int/features/factfiles/food_safety/en/.

crops becomes trickier. The expansion of the global food supply chain threatens safety of food by subjecting food to longer travel times and distances and consequently more opportunities for food to interact with a contaminant. Perhaps most worrisome, the issue of parasitic and otherwise harmful organisms becoming immune to fertilizers and other treatments for plants is rapidly developing. This phenomenon stymies efforts to protect crops and leaves them vulnerable to a host of contamination threats.[33] These dangers, along with several others, demonstrate how imperative it is to make progressions in food safety across the global community.

The Role of Energy in Food Refinement

Status Quo

Food refinement is often an energy intensive process, as foods require thorough processes to maintain their optimal conditions. Washing foods, for instance, is often impossible without energy. The key ingredient in this process of course is water, which helps remove major health threats from food. Procuring clean water oftentimes requires a mechanized pump or filtration system that in turn requires energy. Particularly in rural villages where running water is not a given, energy can help ensure that clean water can be consistently drawn. Additionally, in maintaining the quality of food, heat often plays a vital role. Heat is necessary to boil food, a process that is used to kill bacteria that may be lingering.[21] Just like water, heat requires energy in order to be effective. Although fires can often act as substitutes for more modern heating apparatuses, farms that wish to produce larger quantities of food require industrial sized stoves and boilers in order to clean harvested crops. So, the role of heat in food refinement still relies upon some sort of energy.

[33] World Health Organization, "Food Safety," *World Health Organization*, December 2015 Accessed June 6, 2016, http://www.who.int/mediacentre/factsheets/fs399/en/.

Integrating Energy

The introduction of electricity helps keep crops safe and clean. The ability to create variable temperatures, either through air conditioning or through stoves and heating devices, can keep produce cool to stave off spoilage or heat agricultural goods in order to kill off bacteria. Additionally, the introduction of energy oftentimes makes water more accessible. Energy can be used to pump water out of the ground or to filter and desalinate readily available water. New, portable water filtration systems run on clean energy (most frequently solar) and can produce hundreds of gallons of fresh water per day that can be used to clean livestock and crops.[34] Developing these and other technological advancements can dramatically improve the way food is maintained and transported; but, the implementation of energy systems remains a key prerequisite to realizing any of these benefits.

As with other stages in the food circulation cycle, implementing energy is good, but implementing sustainable energy is astronomically better. Switching to more efficient and cleaner energy in food sanitation will result in several advantages, namely the reduction of environmental and economic costs.

Food Distribution

Arguably the most tragic paradox of today, hundreds of millions of people suffer from severe undernourishment across the globe while 1.3 billion tons of food with a total economic impact of $750 billion is wasted annually. Heavily faulted for this sad reality is the much maligned process of food distribution.

[34] Sonia Kolesnikov-Jessop, "New Technology Could Make Desalination More Accessible," *The New York Times* (New York, NY), March 21, 2011.

Food distribution is the process of moving food from their origins (i.e. farms) to locations that are accessible to consumers, such as stores and markets. This process requires advanced planning and communication along with serviceable transportation infrastructure throughout the supply chain. Additionally, because food is often perishable, distribution is time-sensitive and has little room for error and delay. Many believe that the lack of a comprehensive food distribution system that reaches all areas of the world is the primary force behind food insecurity.

Indeed, the most fundamental challenge in the food distribution process is to ship produce from the site at which it is readied to sell to the market where it is ultimately sold. A common problem in this stage is a lack of access to markets, whether because the market is difficult to travel to or because there is no market. Lack of market access disproportionately affects rural areas, where food must be channeled into larger, more developed areas with markets. This ultimately causes an unequal distribution of food.[35] Oftentimes with famished populations next door, 28% of the world's agricultural land is used to produce food that ends up wasted.[36]

Food distribution has been identified as a clear hindrance to equitable food circulation. However, efforts to solve this issue face a multitude of obstacles. Rural areas, home to roughly 75% of "hungry people," lack even the most basic transportation infrastructure.[37] One billion rural dwellers, about a third of the total rural population, lack adequate transportation. This figure worsens when poorer regions, which also have higher rates of food insecurity, are examined. For example, in Sub-Saharan Africa, nearly two-thirds of the rural population does

[35] Mission 2014: Feeding the World, "Inadequate Food Distribution Systems," *Massachusetts Institute of Technology*, 2014, Accessed June, 23, 2016, http://12.000.scripts.mit.edu/mission2014/problems/inadequate-food-distribution-systems.
[36] Food and Agriculture Organization of the United Nations, "Food Wastage: Key Facts and Figures," *FAO*, 2016, Accessed June 23, 2016, http://www.fao.org/news/story/en/item/196402/icode/.
[37] World Food Programme, "Who are the Hungry?", *World Food Programme*, 2016, Accessed June 23, 2016, https://www.wfp.org/hunger/who-are.

not have access to transportation.[38] Even when food is brought to regions with food scarcities, distributing it can still be challenging. In developing regions, the number of retail stores and wholesale markets for food has not increased at the same pace of food demand. Suppliers need to sell to an intermediary who can compensate the supplier and then pass on food to consumers. These intermediary sellers are crucial because suppliers cannot individually deliver food to thousands of houses nor can they simply drop off food to an uncontrolled location.[39]. Without intermediaries, most suppliers are unlikely to bring their goods to an area.

Despite sufficient transportation and market infrastructure, there remains the issue of protean supply chains that are constantly adapting to technological advancements, changing demographics, and minute details like weather.[40] Supply chains, as they become more modern, are becoming longer; each addition to the supply chain requires new resources that developing areas may or may not have at their disposal. Thus, in addition to both transportation and retail infrastructure, regions grappling with hunger must also be equipped to adapt to constant change if they wish to improve the state of food distribution.

The Role of Energy in Food Distribution

Status Quo

Food transportation can be further categorized into two sections: transportation and transportation planning. The transportation part includes the physical movements of goods from origin to destination. Here, energy is almost solely used to transport food in trucks, planes, trains, ships, and other large vehicles. Although the first solar plane has now successfully crossed the

[38] The World Bank Group, "The Rural Access Index," *The World Bank Group*, 2007, Accessed June 23, 2016, http://www.worldbank.org/transport/transportresults/headline/rural-access.html.
[39] Food and Agriculture Organization of the United Nations. *Urban Food Security and Food Marketing.* FAO. Accessed June 23, 2016.
[40] Reardon, Thomas A. *Growing Food for Growing Cities: Transforming Food Systems in an Urbanizing World*. Chicago: The Chicago Council on Global Affairs, 2016.

Atlantic Ocean and although electric cars have become less of a fantasy, this sector is far from moving away from the current conventional fuels it uses.[41] So, for physical transportation, incorporation of energy will likely be along the lines of increasing access to oil and gas in order for vehicles to reach areas struggling with food scarcity. Developing transportation planning capabilities, particularly in impoverished areas, holds potential for more creativity. In planning, in addition to ensuring that all transportation plans have adequate energy to function, communication systems must be set up. These systems all require electricity, which can be produced using a myriad of different sustainable energy sources depending on the locality and the resources at hand. In any case, to plan and execute proper food transportation, energy is required through every step of the process.

Integrating Energy

The most promising opportunity in bringing energy to the food distribution lies in connecting farms to the global commerce network. In order to successfully do this, farms must gain access to the internet and other related networks. The broadly termed Internet of Things (IoT), which encompasses all of these networks and channels, is predicted to contribute $100 billion worth of advancements to the global agriculture industry per year until at least 2025.[42] Farms without access to electricity and the internet stand to miss out on perhaps the greatest opportunity to ever approach agriculture. The IoT holds the potential to help farmers access markets effectively by granting them information about where markets are, what market demands are, and when markets will be receptive to their goods. This way, food distribution efforts can be more effectively planned in advance. The IoT also has the ability to direct logistics

[41] Levine, Steve. "The Car of the Future May Run on Gasoline." The Wall Street Journal, January 30, 2015.
[42] Castillo, Andrea and Adam Thierer. *Project the Growth and Economic Impact of The Internet of Things.* Arlington: The Mercatus Center. http://mercatus.org/sites/default/files/IoT-EP-v3.pdf .

in food production, removing the unpredictable element in selling goods by allowing farmers to know in advance the precise route of their agricultural transactions.

Food Storage

Food storage provides the crucial capability to lengthen the life span of food and make large harvests useful instead of wasteful. Without food storage, consumers need constant food production, which is extremely difficult to actualize due to seasonal weather changes. Food storage plays its role during three parts of food circulation: post-harvest, transportation, and home use. Directly after harvest, food must be stored in an appropriate environment (varies by crop) with proper levels of humidity, temperature, and ventilations. Failure to do so can deteriorate the health and safety of the crop. During transport, food against must be stored in their appropriate environments for the same reasons. Also, extra safety measures need to be taken in order to prevent damage to the products as they are moving around in transport.[43] Finally, as food reaches consumers and households, once again it must stay in its proper environment in order to retain freshness, health, and safety. This is generally achieved either by refrigeration, where foods are left in controlled climates, or by canning, where foods are left in a vacuum with minimal external chemical interaction.[44] Any break in proper storage can severely deteriorate food and subsequently harm its consumers.

Food storage is also vital because it lessens the intensity of other parts of food circulation. The ability to safely store food reduces waste at the source of production, effectively increasing crop yields. Proper food storage alleviates the burden of food transportation by allowing for a

[43] Food and Agriculture Organization of the United Nations, "Reduction of losses during transport," *FAO,* Accessed August 12, 2016, http://www.fao.org/docrep/t0073e/T0073E05.htm.
[44] The World Health Organization, "Food Safety: What you should know," *The World Health Organization*, April 7, 2015, Accessed August 12, 2016, http://www.searo.who.int/entity/world_health_day/2015/whd-what-you-should-know/en/#preservation.

few large deliveries instead of many small ones; food storage during transportation also increases the distances that crops can be transported without rotting. Also, storing food reduces the necessity of adding preservatives and other chemicals to keep food fresh and safe, taking pressure off of intensive food safety measures. Thus, an investment of energy in food storage stands to reduce energy needs in several other food circulation tasks.

Insufficient storage is a primary cause of food wastages and food shortages. The impact of poor storage in the food circulation process begins immediately after harvest. While processing the initial harvest, 18% of fruits and vegetables, 7% of cereals, and 16% of roots and tubers (e.g. carrots, potatoes) are lost due to improper storage.[45] Some reports have documented that throughout food circulation, developing countries such as India adequately and safely store just 10% of certain food groups. Particularly, there are serious shortcomings in cold storage, which is crucial for every major food group aside from grain. Ultimately, some estimates for countries like India note that food storage capacities must increase by 40% in order to mitigate food wastage.[46] Even in completely developed countries, food storage is imperfect. In the US, two-thirds of food wastage in households (which constitutes about half of total waste in the US) occurs in large part due to ineffective storage that causes foods to spoil.[47]

In addition to making harvests more efficient and keeping food fresh as it travels from the farm to the household, food storage - or rather lack thereof - has to potential to be a great deterrent for food circulation. If suppliers feel that they cannot transport their produce to a region without risking spoilage, they will not supply that area. This harms rural areas and small market areas the most. These areas are the most likely to be distant and to not have the economic allure

[45] Rockefeller Foundation, "Waste and Spoilage in the Food Chain" (Decision Intelligence Document, Rockefeller Foundation, 2013).
[46] Emerson Climate Technologies. *The Food Wastage and Cold Storage Infrastructure Relationship in India*. Pune: Emerson Climate Technologies, 2013.
[47] GRACE Communications Foundation, "Food Waste," *GRACE Communications Foundation*, 2016, Accessed June 23, 2016, http://www.sustainabletable.org/5664/food-waste.

necessary for suppliers to relocate themselves around. If food storage, both in transportation and within households, can improve, the supply radius for agricultural producers and the ability to retain food will increase, bringing and keeping food in vulnerable areas.

The main challenges that face innovators in food storage are technological and economic challenges. Regarding technological challenges, as supply chances continue to grow and change, food storage must become more reliable in an increasingly unreliable world; this means that food storage must last longer, survive harsher weather, and must protect a wider variety of foods. However, technological growth is promising. For example, the US Department of Agriculture has developed a moisture-retaining package that can double the storage life of small fruits.[48] Additionally, a wide variety of developments have been made in portable refrigerators and other cold storage technologies. The other issue that remains is the high cost of these technologies, which often precludes benefits from reaching developing countries, rural areas, and the other regions that suffer most from food scarcity. Today, rising fossil fuel prices increase the cost of transporting and storing food using conventional machinery. Additionally, volatile commodity costs often give price shocks that are too drastic for impoverished regions to handle, leaving them to cut back on consumption. Accordingly, many experts are recommending that sustainable technologies be used in order to avoid the aforementioned issues with conventional technologies and to keep up the fight against Food Insecurity.[49]

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[48] Jean C. Buzby, Hodan Farah Wells, and Jaspreet Aulakh, "Food Loss—Questions About the Amount and Causes Still Remain," *US Department of Agriculture,* 2014, Accessed June 23, 2016, http://www.ers.usda.gov/amber-waves/2014-june/food-loss%E2%80%94questions-about-the-amount-and-causes-still-remain.aspx#.V2wPB7grKUk.

[49] Nick Houtman, "Rising Fossil Fuel Energy Costs Spell Trouble for Global Food Security," *Oregon State University: News and Research Communications,* 2015, Accessed June 23, 2016, http://oregonstate.edu/ua/ncs/archives/2015/jul/rising-fossil-fuel-energy-costs-spell-trouble-global-food-security.

The Role of Energy in Food Storage

Status Quo

Food storage is an extremely energy-intensive task. Every kilogram of retail food requires between one to three million joules of energy for storage, mostly in the form of refrigeration.[50]

Energy in food storage is useful mostly in the form of electricity, which provides power for refrigerators and other temperature controlled storage devices. Electricity for this use must be consistent and sustainable. A loss of electricity for just 20 minutes can lead to a doubling of malicious bacteria in common foods and certain foods can become unsafe to consume after just 2 hours in temperature above 40 degrees Fahrenheit.[51] The dependence of many foods on staying cold, initiates cold chains, which are planned transportations of produce where the produce are never subjected to warm or even room-temperature conditions. Many short-distance cold chains can survive by using liquid nitrogen, dry ice, or gel packs to keep good cool. However, these resources only remain effective for finite amounts of time. Long-distance cold chains are becoming increasingly common with globalization, and reefers, which are controlled and low temperature containers, are more common. The share of reefer use in maritime refrigerated transport has risen to 90%, and general utilization of reefers in storage is becoming increasingly ubiquitous.[52] Reefer use increases the importance of energy in food storage as reefers require electricity to function, which is usually provided by a generator or by the transport vehicle.

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[50] Food and Agriculture Organization of the United Nations. *The Case for Energy-Smart Food Systems*. FAO, 2011.
[51] Food Safety and Inspection Service, "Refrigeration and Food Safety," *United States Department of Agriculture,* 2015, Accessed June 24, 2016, http://www.fsis.usda.gov/wps/portal/fsis/topics/food-safety-education/get-answers/food-safety-fact-sheets/safe-food-handling/refrigeration-and-food-safety/ct_index#2.
[52] Comtois, Claude, Jean-Paul Rodrigue, and Brian Slack. *The Geography of Transport Systems*.New York: Routledge, 2013.

Ensuring energy throughout cold chains must become a priority, particularly in developing countries where 23% of food is wasted due to breaks in cold chains.[53] Securing consistent energy at the destinations of food distributions is equally important to make certain that a healthy amount of produce can be collected and eventually eaten without deterioration in quality.

Integration of Energy

When it comes to food storage, energy plays a critical role in powering cold chains and household refrigeration. Energy is required consistently throughout long-distance cold chains and oftentimes during portions of short-distance cold chains. Given that produce in cold-chains are constantly moving, energy for cold-chains must be mobile and portable. Therefore, energy storage devices are crucial and the development of these technologies will allow for more consistent function of reefers and portable refrigeration containers. Direct Drive refrigerators, for example, utilize solar power to freeze water or similar substances that then can be used as a source of cold to retain low temperatures in mobile storage.[54] Conventional energy sources such as coal and oil are available, but, as seen in other food circulation stages, are subject to varying commodity prices and also are harmful to the environment. Natural gas has been touted as a cost-effective and powerful energy source; but, natural gas remains a detriment to the environment and still requires extensive infrastructure to extract Solar power is one of the most sustainable energy sources and the global capacity for solar energy is increasing rapidly. Other sources such as geothermal energy and hydropower have their own merits, further establishing sustainable

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[53] European Fluorocarbons Technical Committee, "The Importance of Refrigeration to Reduce Global Food Waste," *EFCTC,* 2016, Accessed June 24, 2016, http://www.fluorocarbons.org/mediaroom/665/74/The-Importance-Of-Refrigeration-To-Reduce-Global-Food-Waste.

[54] The World Health Organization and Path. *Direct-drive solar vaccine refrigerators— a new choice for vaccine storage.* May 2013. Accessed August 12, 2016. http://www.who.int/immunization/programmes_systems/supply_chain/optimize/direct_drive_solar_vaccine_refrigerator.pdf.

energies as the superior type of energy source.[55] Ultimately, while the best source of energy will depend on the available resources, political factors, and societal preferences of a certain area, sustainable energies undoubtedly present more environmental, economic, and logistical benefits – particularly in the long run – compared to their non-renewable counterparts. The same principles applied to the development of energy in cold-chains can be applied to the development of energy for household refrigeration with the only omission being that household refrigeration systems stay put. This key difference makes renewable energies such as hydroelectric, solar, and wind energy more viable because these energy systems can be stationed in an optimal location without having to give up that spot. Additionally, energy transfers will be more efficient for household refrigeration because energy does not need to be stored over long periods of time. Again, the optimal source of energy will vary from region to region; but, what will persist in all places is the importance refrigeration has as an asset in reducing food wastage and increasing food access.

Limitations of Increasing the Role of Energy in Food Circulation

Economic

The economic limitations of bringing energy into the agricultural world are significant. The regions that suffer the most from hunger are also the regions that suffer the most from poverty. Hence, an unfortunate hunger-poverty trap is created in which poor populations struggle to produce or import enough food, which further reduces productivity and eventually worsens

[55] Todd Myers, "The Experts: What Renewable Energy Source Has the Most Promise?" The Wall Street Journal, April 17, 2013.

poverty.[56] In order to break this downward spiral, these areas need foreign aid or drastic economic stimulation. However, pulling every poor and hungry population out of the hunger-poverty trap is considered a daunting endeavor and raising the money to do so requires clearing many political and economic obstacles. Developing energy systems in impoverished areas, which undoubtedly relieves economic pressures and increases production capacities in those areas, requires significant time and resources. Truly sustainable energy systems also oftentimes require the local populations to be trained in order to independently operate and maintain their infrastructure. All told, setting up energy in order to mitigate the effects of hunger requires an unwavering commitment of time, labor, and resources from a party dedicating to enacting positive change.[57] Unfortunately, it is this commitment and dedication that is lacking as a result of insufficient interest, attention and available resources.

Sociopolitical

Sociopolitical instability is widely considered a spark to yet another cyclical cause of persistent Food Insecurity. In this cycle, conflict, either civilian or institutionalized (e.g. military), prevents the development of a thriving economic system, energy system, agricultural system, and also deters foreign intervention even when entire populations are suffering from food and energy shortages. Out of all the food-insecure people in the world, 65% of them live in just seven countries. Six of the seven countries have experienced civil or institutionalized conflict in the 21st century, with the only exception being China.[58] Similarly, political instability

[56] Food and Agriculture Organization of the United Nations. *Reducing Poverty and Hunger: The Critical Role Of Financing For Food, Agriculture And Rural Development*. Monterrey, Mexico: FAO, March 2002. Accessed August 12, 2016. ftp://ftp.fao.org/docrep/fao/003/Y6265E/Y6265E.pdf.
[57] United Nations News Centre, "'Hunger is more than a lack of food – it is a terrible injustice,' says Ban on World Food Day," *The United Nations*, October 16, 2015, Accessed August 12, 2016, http://www.un.org/apps/news/story.asp?NewsID=52282#.V63jmZgrKUl.
[58] Brinkman, Henk-Jan and Cullen S. Hendrix. *Food Insecurity and Violent Conflict: Causes, Consequences, and Addressing the Challenges*. World Food Programme, 2011. Accessed August 12, 2016.

and conflict also propagate Energy Poverty. Due to the specific infrastructure required to produce energy, impoverished areas suffering from Energy Poverty require strong political leadership and initiative, which is often nonexistent in impoverished areas suffering from political instability.[59] Thus, sociopolitical instability, which tends to thrive in impoverished areas, serves as a major impediment to energy development and establishment of food security.

Conclusion

It is vital to pursue the implementation and improvement of energy systems throughout the world in order to combat food insecurity. Throughout the four major stages of food circulation (production, refinement, transportation, and storage), energy plays a vital role. Without access to energy, the food circulation system would falter. Without the expansion of energy systems, food circulation cannot grow to diminish food insecurity. Therefore, experts and citizens alike ought to endorse the implementation of energy systems in places without energy and the enhancement of energy systems in places that have insufficient energy infrastructure.

While injecting energy into food circulation does have the potential to improve every facet of the process, it must be understood that the advent of energy in farming will drastically change how farmers operate. It is important that prior to major changes, farmers ready themselves to adapt. Energizing farms will increase the need for labor and will increase the necessity for access to markets as more goods will be produced. Additionally, energy must be sustained to prevent drastic dips in production and the increased wealth incurred by farmers must be spread fairly evenly across the region and across different demographics (e.g. gender).[21] In

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http://documents.wfp.org/stellent/groups/public/documents/newsroom/wfp238358.pdf?_ga=1.213196564.1898777680.1466694497.

[59] Allan R. Hoffman, "Energy Poverty and Security," *Journal of Energy Security* (April 2009).

short, farmers must literally be able to reap what they sow, must be able to manage increases in wealth, and must embrace their new role in globalization.

Ultimately, the global community cannot stand idly and watch millions of fellow global citizens starve while solutions and means of improvement lie in plain sight. The global community cannot be complacent and it cannot ignore the importance of the role of energy as an anecdote to food insecurity. The energy development and food security landscape warrants cautious optimism, but the onus remains on the international community to wield this instrument in the fight against one of the most lethal killers in the world.