Feeding Everyone if Industry is Disabled

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ABSTRACT: A number of risks could cause widespread electrical failure, including a series of high-altitude electromagnetic pulses (HEMPs) caused by nuclear weapons, an extreme solar storm, and a coordinated cyber attack. Since modern industry depends on electricity, it is likely there would be a collapse of the functioning of industry and machines in these scenarios. As our current high agricultural productivity depends on industry (e.g. for fertilizers) it has been assumed that there would be mass starvation in these scenarios. We model the loss in current agricultural output due to losing industry. Then we analyze compensating strategies such as reducing edible food fed to animals and turned into biofuels, reducing food waste, burning wood in landfills for energy, phosphorus, and potassium, and planting a high fraction of legumes to fix nitrogen. We find that these techniques could feed everyone, and extracting calories from agricultural residues, fishing with wind-powered ships and expanding planted area could feed everyone several times over.

***Keywords*: solar storm, high-altitude electromagnetic pulse, computer virus, global catastrophic risk, existential risk, industry, food, electricity**

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1. INTRODUCTION

There are several human-caused and natural catastrophes that could result in global-scale temporary long-term electrical grid failure, which would be expected to halt the majority of industries and machines. A high-altitude electromagnetic pulse (HEMP) caused by a nuclear weapon could disable electricity over part of a continent (Foster et al., 2004). It is conceivable that multiple HEMPs could be detonated around the world, due to a world nuclear war or due to terrorists commandeering nuclear weapons. This could destroy the majority of electrical grid infrastructure globally, and as fossil fuel extraction and industry is reliant on electricity (Foster, Jr et al., 2008), industry would be disabled. Similarly, solar storms have destroyed electrical transformers connected to long transmission lines in the past (Board, 2008). There is evidence that within the last 2000 years, two solar storms occurred that were much more intense than modern society has endured (Mekhaldi et al., 2015). Though solar storms may last less than the 12 hours one might think would be required to expose the entire earth, the earth's magnetic field lines redirect the storm to affect the opposite side of the earth (Board, 2008). Therefore, it is possible that an extreme solar storm could disable electricity and therefore industry globally. Finally, cyber attacks could compromise the electric grids. Stuxnet was a computer virus that destroyed Iranian centrifuges (Kushner, 2013) to disable their nuclear industry. There is also evidence that a computer virus disrupted electricity in the Ukraine (Goodin, 2016). It is conceivable that a coordinated attack on many electric grids could also disrupt industry globally. As our current high agricultural productivity depends on industry (e.g. for fertilizers) it is has been assumed that there would be mass starvation in these scenarios (Robinson, 2007).

Repairing these systems and re-establishing electrical infrastructure would be a goal of the long term and work would start on it immediately after a catastrophe. However, human needs would need to be met immediately (and continually) and thus to remain conservative we consider the scenario of industry being disrupted indefinitely. We leave the actual recovery time (and mechanisms) from various catastrophes for future work (though we note that on continents with excess people relative to food growing capacity, the excess people would have greater resources to restore industry). In some of the less challenging scenarios, it may be possible to continue running the majority of machines on the fossil fuels that had previously been brought to the surface or from the use microgrids or shielded electrical systems. In addition, it may be possible to run some machines on gasified wood (Dartnell, 2014). However, in the worst-case scenario, all existing un-shielded electronics would be destroyed, so to address this challenge we conservatively assume that no electrical machines will function immediately after the catastrophe. Here we focus on what is technically possible, and leave economics and politics for future work.

2. ESTIMATING AGRICULTURAL PRODUCTIVITY WITHOUT INDUSTRY

One way of estimating the impact of losing industry on agricultural productivity is examining this productivity before the Industrial Revolution. The rice yield per hectare in Japan in 1870 was approximately 40% lower than the global average value in 2000, while the wheat yield per hectare in the U.S. in 1860 was approximately 70% lower than the global average in 2000 (Lomborg, 2001). The Industrial Revolution in the U.S. preceded 1860, but the productivity growth from 1860 to 1940 was only about 15%. There has also been some improvement in global productivity since 2000. Therefore, we estimate that preindustrial productivity was approximately 60% lower than the current global average.

There are several reasons why agricultural productivity given the sudden loss of industry may be higher than preindustrial, and several reasons why it could be lower. On the higher side, humanity has learned techniques not dependent on industry in the last 150 years. For example, the role of fertilizers is now well understood, and farmers can return the nutrients from human waste to the farm fields as was done in directly in China (McClintock, 2010) and with reduced pathogen transfer using composting techniques on even the small scale (Jenkins et al., 2005). Also, society has developed integrated pest management strategies that do not rely on industrial pesticides (Pimbert, 1991). The supply of draft animals would also be higher per hectare now (see below). One way of seeing what society has learned is the fact that there is a raging debate of the productivity of organic agriculture compared to conventional agriculture, where some find that it is only about 25% lower land productivity than conventional agriculture (Seufert et al., 2012), others find organic agriculture higher (Lansink et al., 2002) and some studies find approximate equivalence (Posner et al., 2008). It is not realistic to expect full current organic productivity without industry because now nutrients can be imported from other places, tractors can be used, and even some naturally occurring pesticide compounds that are synthesized by industry can be used. But still it may be reasonable to expect significantly smaller than a 60% drop in productivity due to losing industry.

However, on the negative side relative to preindustrial agricultural productivity, most people who will be needed to farm by hand do not know how to farm by hand nor are they accustomed to physical labor. Furthermore, it will take some time to construct appropriate farm tools. In addition, there may be inadequate labor in some regions. Finally, some land that is currently farmed may be infertile without industry, such as land that is mechanically irrigated. However, these issues will generally be short-lived, and current storage could help to bridge the gap. To remain conservative, we assume preindustrial agricultural productivity.

3. FARMING WITHOUT INDUSTRY

First we estimate the current food production. Grain production is ~2.7 billion tons (Gt)/yr (Tilman et al., 2002), and grains are ~29% total of fiber and moisture (Hurburgh, 2006; United States Department of Agriculture, 2006). Thus, this is ~1.9 Gt/yr dry carbohydrate equivalent. Grains make up roughly half of the calories produced (Meadows et al., 2004); therefore, the total food production is ~3.8 Gt dry/yr. A step to increase food supply is reducing the postharvest losses, which are currently ~35% (Godfray et al., 2010). This includes improving harvest, storage, and transportation systems. The harvest losses with mechanization are large, but the labor savings offset this economically (Kantor et al., 1997). Therefore, without industry, farmers would use more labor-intensive harvesting techniques, which would have the benefit of reducing losses. Loss reduction also includes reduction of waste in retailing and household use, which people can implement even more rapidly. Though the loss of refrigeration would be a significant setback in terms of the overall food system, drying of food would both reduce its transportation weight and preserve it. Drying can be achieved by burning local biomass. Therefore, we assume a reduction in these types of wastes of a factor of two.

Another step is reducing the amount of losses of edible food fed to livestock and pets and used to produce biofuels. We assume the catastrophe will make these food losses negligible, especially because farmers would still produce some animal products on land that is unfit for human food production directly and on cellulosic food residues (eating draft animals at the end of their useful life). Non-draft animals would be quickly killed and dried with biomass fires to preserve the meat.

For fertilizer, we will focus on potassium, phosphorus and nitrogen. There is a tremendous reservoir of organic material in landfills that has not decomposed, such as wood construction waste. This would not be a desirable source of food directly by the conversion of cellulose (Denkenberger and Pearce, 2014). However, if it can be burned (possibly as an energy source), the resulting ash would be rich in potassium, but unfortunately low in phosphorus (Karoline, 2012). Generally, landfills would not be too far away from farm fields, so transportation should not be difficult. If the loss of industry is extended, the current housing stock would be excessive. Therefore, as buildings deteriorate, they could also be used as a fertilizer source. In either case, lead paint would be problematic, though it could be removed. Polymer binders in plywood, oriented strand board, and particleboard would likely be acceptable if combusted completely. If the phosphorus from these sources is insufficient, additional sources include the waste material from converting leaves and wood into alternate foods (see Options For Feeding More People). Unfortunately, combustion releases the nitrogen in the form of gases, so another source of nitrogen must be found. Nitrogen can be recycled from human and animal wastes. However, inevitably there will be some loss of nitrogen through runoff and volatilization (conversion to a gaseous form). Fortunately, legumes (beans, peas, peanuts, etc.) harbor nitrogen-fixing bacteria in their roots. The ideal scenario would be planting these legumes next to other crops, as Native Americans did (Staller et al., 2009). This is because the nitrogen could be released to the other crops even during the growing season (Mann, 2011). Legumes tend to be high protein, which is advantageous with the nearly vegan diet. However, the nitrogen levels will still be lower than with application of chemical fertilizers, which would reduce yields.

Draft animals require food, though this generally could come from non-edible agricultural residues. There are 1400 million cattle in the world (Crutzen, 2006). Though many of these are dairy cows, they could still perform some work. Also, other animals could be used for farming, such as horses, mules, donkeys, llamas, alpacas, camels, elephants, yaks, water buffalo, and reindeer. Some of these would be required for inland transport, but we assume the number of cattle would be representative of the amount of work that could be done by a preindustrial draft animal. The global cultivated (not grazed) area is 17.25 million km^2 (World Geography 2016, CIA World Factbook, 2016). This yields 1.23 hectare cultivated per draft animal. A typical preindustrial value was 7.4 hectares per draft animal (Prak, 2001). This means there would be a significant excess of draft animals, even if cultivated area is expanded (see Expanding Planted Area). This would allow some of these animals to be used for grazing. Some relocation of draft animals would be beneficial and feasible (since the relocation of people is feasible by an order of magnitude (Abdelkhaliq et al., 2016)).

In order to convert back to a non-industrial farm, equipment such as plows will need to be fabricated. This could be done with iron from landfills or even wood. Animals could perform additional tasks, such as pulling harvesting machines. This would allow a single farmer to feed many people, but would probably not happen until several years after the catastrophe.

Though genetic modification would cease, it may be possible to continue using improved varieties indefinitely. For pest management, biological control could be used. Furthermore, even hot water can kill some pests. If preindustrial productivity were assumed, it could meet 115% of human requirement.

Table 1 shows the estimated agricultural productivity as a percent of preindustrial. European wheat is approximately 7 times preindustrial productivity and U.S. productivity is similar to global (Lomborg, 2001). Asia and South America underwent the green revolution, roughly doubling productivity. However, African productivity has lagged.

Table 1. Productivity as percent of preindustrial, number of people relocated from and to, and months of storage for each continent

Continent	Productivity as % of preindustrial	Number of people to be relocated from (million)	Number of people to be relocated to (million)	Months of food storage	Total consumption per person without industry (kcal/day)
N. America	240%	0	400	9.7	5500
S. America	200%	0	0	5.0	3300
Europe	700%	280	0	6.9	1300
Asia	200%	0	0	3.4	2200
Oceania	240%	0	40	13.2	7400
Africa	130%	160	0	1.7	1800
Total	230%	440	440	4.1	2400

One difficulty is that there would be excess people in some parts of the world (Europe and Africa), and possibly a deficit of people to farm the land in other areas (North America and Oceania). This challenge can be solved by relocation of people even in such extreme situations as complete lack of electrically-dependent industry (Abdelkhaliq et al., 2016). Following (Abdelkhaliq et al., 2016), Table 1 also shows the number of people to be moved from and to different continents and the food produced per person on each continent. Since grain is inexpensive and relatively easy to store, it likely makes up the majority of food storage. The minimum global wheat storage is ~2 months at current wheat consumption (Do et al., 2010), and we assume that this applies for all grains. Given that global grain production is ∼1.9 Gt/yr dry carbohydrate, and that human consumption is approximately 1.5 Gt/yr, this gives approximately 3 months of human consumption. In addition, we estimate that there is a 1-month supply at crisis levels of consumption of food total in the following locations: households, stores, and warehouses. Therefore, we estimate four months of storage at near vegan and low waste consumption globally. We assume that this storage is distributed on the continents based on grain production. Table 1 also shows the number of months of storage for each continent.

To maximize the time allowed to relocate people, the ships returning to the locations of excess population should be filled with grain. The majority of people that would need to be relocated would be moving from Europe to North America, and Paris to New York City is only about 6000 km (Port distance, 2016). However, given that sea transport will be much lower cost than land transport (Abdelkhaliq et al., 2016), ships will be favored. For instance, since Oceania can absorb a minority of the required African flow, a common route could be Eastern Africa to the Gulf of Mexico (Nairobi, Kenya to Houston, U.S. is approximately 18,000 km by ship (Port distance, 2016)). Therefore, we consider 12,000 km as a typical ocean distance. The relocation of people would be feasible with wind powered ships by an order of magnitude (Abdelkhaliq et al., 2016).

4. OPTIONS FOR FEEDING MORE PEOPLE

In previous work, alternate foods such as mushrooms growing on trees and bacteria growing on natural gas were found to be sufficient to feed everyone even if the sun were mostly blocked (Baum et al., 2016). However, this was assuming that industry was still functioning. Without industry, these solutions become more challenging but some are feasible (Denkenberger et al., 2016).

Another method we do not quantify is converting some of the land that currently undergoes grazing to farming. Because some of the plant matter would go directly to humans, this would be more efficient. Society could also reduce the acreage devoted to nonfood plants (such as tobacco and lawns) and those plants that produce lower calories per hectare (such as coffee). Similarly, high productivity plants could be favored, like sugarcane and potatoes.

5. EXPANDING PLANTED AREA

The preceding calculations indicate that humanity's food needs could be relatively easily maintained even with a protracted lack of electricity and industry. However, even in the event that the techniques outlined above were inadequate in a region, planted area could be expanded by deforestation. This should only be used if other options are exhausted. Cutting down the entire forested area would be feasible in one year with industry (Denkenberger and Pearce, 2015). However, it would not be feasible without industry. Nonetheless, it would be relatively easy to girdle (remove a strip of bark completely around the base of) trees to kill them. After the trees dry out, they could be burned. A concern is that the smoke could enter the stratosphere and cause global climate change, like in the case of nuclear winter (Robock et al., 2007). Even when there is no fire, a strong thunderstorm can inject air from near the surface into the stratosphere (Fischer et al., 2003). However, this scenario could be avoided by setting fires when atmospheric conditions are more stable. Of course forest fires can burn for a long time, so only girdling trees in limited areas could help to limit the fire spread. In addition, efforts should be made to reduce the net biodiversity impact as starving people would engage in desperate behavior, such as eating species to death. Damage to biodiversity could be limited by first clearing areas of forest that have already been cleared (not old growth), which would also limit the carbon dioxide production because of the shorter trees. Also, forests could be cleared in areas that have low biodiversity. Endangered plants and animals could be relocated or even put in captivity. As a last resort, seeds and eggs could be stored in natural low temperature storage like at the Svalbard seed vault (Fowler, 2008).

The global forested area is 40 million km^2 (Food and Agriculture Organization, 2000). Generally, areas that are forested have sufficient precipitation and temperature to be cultivated. Therefore, a rough approximation of the increase in food output associated with clearing all the forests would be 230%. Some food production comes from grazing currently, but grazing could also be expanded into natural grasslands. Therefore, if all of the forests were cleared, 380% of food requirement could be met.

6. ADDED VALUE FOR INTEGRATIVE RISK MANAGEMENT AND URBAN RESILIENCE

In the Hyogo Framework for Action, this work supports preparedness and identifying risks. However, in order to be prepared, these solutions for industrial loss must be distributed (because of the loss of communication), so this is a gap in the Post 2015 Framework for Disaster Risk Reduction. Training for the scenarios considered here could be done at the same time that other training is done. Given the loss of industry, many people would need to vacate the cities in favor of the farmland. However, for those remaining, it is possible to provide food.

7. CONCLUSIONS/FUTURE WORK

If industry is disabled abruptly, the impact on agricultural output is complex, but here where it is conservatively assumed that it equals preindustrial agricultural productivity, it is found that conventional farming would be sufficient to feed everyone with some relocations. In reality, with all the other food sources considered, relocation would likely not be required, at least between continents.

It would be preferable if the loss of industry could be prevented. This could also be achieved by preventing the source of catastrophes such as HEMPS and cyber attacks, although it is not possible for solar storms. Another option is hardening the electrical systems, which would be relatively straightforward in the case of solar storms as it is mainly about protecting transformers. Protecting against HEMPs would be much more expensive because the damage includes electronics connected to the grid and even vehicles. In a small part this can be done by improved electronics shielding to critical equipment and movement to distributed generation of hardened microgrids. Protecting against a coordinate cyber attack would also be difficult, although there is already a considerable literature on improving grid security and such an attack on a global scale would be highly non-trivial. Even if all this prevention and protection is feasible and justified, until it is all implemented, a backup plan is required.

One such backup plan would be storing up food. However, this would not be effective if it took more than a few years to restore industry, would inflate the current price of food (exacerbating current mortality due to undernutrition) and would be very expensive (Baum et al., 2015). Conversely, having a plan for how to feed everyone if industry is disabled along with some targeted research would be very inexpensive.

In order to save almost everyone if industry collapses, people would need to know how to provide their food needs without industry. Depending on the catastrophe, there may be a window of opportunity to distribute this information after a catastrophe although some of them could halt the vast majority of electronic communication. It is preferable if this information were disseminated before the catastrophe. This would reduce the chance of civilization collapsing, from which humanity might not recover. This reduced risk would benefit the far future, which has overwhelming importance (Beckstead, 2013).

Loss of industry locally is considerably more likely, caused by scenarios such as the breakdown of international trade. These techniques could be applied to individual countries that lose industry. Future research includes running experiments and more in-depth simulations on the means to generate food without the use of electricity and conventional industry.

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