Abstract: It is crucial to increase the resilience of the global food production and distribution systems against the growing concerns relating to factors that could cause global catastrophic infrastructure losses, such as nuclear war or a worldwide pandemic. Currently, such an event would result in the global loss of industry, including the ability to drill and refine crude oil. In such an event, the existing above-ground reserves of diesel and gasoline are likely to still be intact but would only be able to power the production and transportation of food between 158 days and 481 days with 80% confidence, where the mean is 195 days at current rates. This paper investigates a novel group of interventions in relation to the scenario of providing food under these conditions. It was found that by using a plausible combination of wood gasification, increasing vehicle utilisation rate, and reducing food consumption, the stockpile duration could increase to between 382 days and 1501 days with 80% confidence, where the mean is 757 days. This is an improvement in mean duration by a factor of 3.9. It was discovered that diesel is the limiting fuel in all scenarios due to wood gas only being a partial replacement for diesel fuel and also because of the prevalence of diesel engines in both the agricultural and trucking industries. A sensitivity analysis was completed identifying that reducing food consumption to minimum levels was the most effective method to prolong diesel reserves. The other factors that benefited from extending fuel reserves in terms of their effectiveness are reducing the lag time before gasification devices are installed, increasing the rate at which gasification devices are installed, and increasing the agricultural equipment utilisation rate.

Keywords: food resilience; electromagnetic pulse; wood gasification; food supply chain; nuclear war; global catastrophic risk; global catastrophic infrastructure loss

1. Introduction

In 1900, 39% of the US working population was engaged in agriculture, a stark contrast to the 2% observed today [1]. This has been made possible only by increasing agricultural labour productivity by more than 50 fold [1]. This shift underscores how vital it is to maintain modern agricultural productivity to sustain the current level of human prosperity. Modern agriculture has proven to be resilient to random localized calamities such as droughts and floods [2]. However, recent studies have highlighted possible large-scale vulnerabilities inherent to the highly complex farming methods used today, which could result in multiple bread basket failures [2,3].

1.1. Agriculture’s Dependence on Fossil Fuels

Central to many of these vulnerabilities is the significant reliance of modern agriculture on fossil fuel resources. Industrialized agriculture requires gigajoules worth of fossil fuel energy to grow a single hectare of crop for one year [4]. The largest agricultural uses of fossil fuels are for the manufacture of inorganic fertilizer (31%), the operation of field machinery (19%), food transportation (16%), and irrigation (13%) [5]. Food transportation is particularly energy intensive due to refrigeration requirements, which is shown by
the fact that although 18% of the global freight ton-km is related to food, food transport produces 27% of all transportation emissions [6].

Thus, the industrial production and distribution of food are heavily reliant on fossil fuels representing a significant failure mode of the global system. Global agriculture, including all upstream supply chain effects and accounting for land use change activities, generates 15.8 GtCO2e [6], which is approximately 30% of the world’s global greenhouse gas emissions of 52.5 GtCO2e [7].

1.2. Global Catastrophic Infrastructure Loss

Multiple, simultaneous, worldwide electromagnetic pulse events (a global EMP) would devastate the infrastructure critical for crude oil extraction and refinement. This would cripple the production of liquid fossil fuels like diesel and gasoline, which are used to power agricultural equipment and irrigation [1]. This event would also cripple fertilizer and pesticide production, both in terms of destroying their production facilities and by preventing access to the fossil fuels required to run those factories [1,8]. This paper investigates using existing fuel reserves and installing wood gasification devices on equipment that would enable the operation of tractors, trucks, and some irrigation pumps. Soybeans are an example of a crop that can maintain high yields under these conditions. Soybean yields are estimated to reduce by 2.6% in the absence of fertiliser and pesticides, but their yields would drop by 55.3% without mechanised labour and irrigation [9].

There are numerous possible causes of global catastrophic infrastructure losses. Taking conservative estimates of modern nuclear weapon yields and numbers [10–13] the global arsenal could cover the entire world with an EMP 90 times over, meaning there are seven countries today that could unilaterally create such an event. However, it should be stated that the limiting factor would be launch vehicles and not the nuclear warheads themselves, which this estimate does not consider. The motivation behind such an action could be to obtain a military victory, as a reaction to a false alarm, or as an asymmetric weapon against AI systems. Solar flares would also have similar results by creating distortions in the Earth’s magnetic field. There is evidence for four solar flares that have the potential to create a global catastrophic infrastructure loss; these happened in the years 1859 AD, 993 AD, 774 AD, and 7176 BC [14,15]. Conventional weapons targeted at key grid vulnerabilities could cause large-scale outages. An extreme pandemic could cause people to be unable or unwilling to work in critical industries, causing the collapse of electricity [16]. The pandemic scenario is more complicated because interventions need to dramatically limit human-to-human transmission of the disease. However, the solutions here generally can be implemented with low contact.

1.3. Global EMP Damages

The energy in the electromagnetic pulse couples with electrical conductors to create large voltage and current spikes. The longer the conductor, the more energy is transferred, and so the long transmission lines of the electrical grid are particularly susceptible. The isolation fuses that protect electrical infrastructure typically cannot protect against the E1 pulse, which is a few nanoseconds in duration and thus will provide no protection. Most things that are connected to the grid during the event, such as fridges at home, lights in hospitals, electric cars that are charging, sensors and motors in factories, and many more devices, will likely be destroyed [1].

Smaller electronic devices have shorter conductors, which generate smaller currents in the presence of an EMP but also sustain damage at smaller currents. However, overall semiconductor chips that are not connected to long conductors, for example, laptops, phones, and Arduinos, are likely but not certain to survive the electromagnetic pulse. Thirty-seven different makes and models of cars with vintages ranging from 1986 to 2002 and eighteen trucks with vintages between 1991 and 2003 were tested under nuclear bomb electromagnetic field like conditions up to 50 kV/m. Only one car and one truck required repair at a mechanic; most received minor damage to things like the indicator
lights, and some were unscathed [1]. Modern vehicles have considerably more of the sensitive semiconductor electronics than cars from the early 2000s, so it is not clear how well they would perform. However, this paper assumes most vehicles would be operational. The electronics required to make trains operational will be destroyed by the large currents that the train tracks will generate. Replacement parts that are not connected to the grid and items in transit, like machinery in cargo containers, will be operational and can be used to regain some industrial capacity.

1.4. Gasification Devices

The gasification process describes the chemical processes that occur when a carbon-based fuel, such as wood, charcoal, or biomass, is burned in an oxygen-limited environment. Keeping the reaction temperature between 700°C and 900°C maximises the useful carbon monoxide and hydrogen yield while minimising the production of tars, which damage engine components [17]. The process is dangerous. Fire escaping the reactor or the flammable gases igniting before they reach the engine pose a risk to equipment and people. The colourless, odorless, and toxic carbon monoxide gas can also leak and build up in the enclosed cab of the car with lethal consequences.

A vehicle gasification device is composed of a reaction chamber, filters, and a heat exchanger [18]. Air passes through the reaction chamber at an oxygen-limiting rate, where it is turned into syngas, which is then fed through a series of filters before entering the engine’s pistons. Gasification can obtain a fuel consumption of 0.1 kg of dry wood per ton kilometer for truck freight and slightly more for car transport [17].

Gasification devices do not require precise tolerances, can be made from common materials such as propane tanks, and can be manufactured with common welding equipment that does not require electricity to operate. Thus, the supply chain to fabricate gasification devices is expected to be resilient against catastrophic global infrastructure loss. The manufacture of engines, even relatively primitive steam engines, requires machining tolerances less than a tenth of a millimetre; as a result, their manufacturing supply chain is far more fragile and is conservatively not considered in this analysis.

2. Methodology

2.1. Gasification Device Installation Rate

The largest historical event of mass vehicle gasification occurred in Sweden during World War II, when oil imports ceased almost completely from April 1940 onward [18]. The country saturated their vehicle fleet with retrofitted wood gasification devices in 15 months [18,19], as shown in Figure 1. Sweden managed to install gasification devices at a rate of 6600 ± 1000 (hp)/day. If this figure is scaled on a population basis, then it suggests a global installed vehicle gasification device rate of 8.3 × 10^6 ± 1.3 × 10^6 hp/day.

There are a number of important differences between the Swedish case study and a global EMP event. Sweden was relatively prepared, largely thanks to the efforts of Axel F. Enström, who laid the groundwork after World War One. He built considerable tacit knowledge throughout industry, oversaw the training of fitters and drivers, set up wood chip supply chains, and had full governmental support. Today, far fewer people have the tacit knowledge of constructing, installing, and operating gasification devices. It is also unclear if communication will be better due to better technology or worse due to most of that technology being destroyed. Likewise, today we can make use of much higher-performance welders and laser cutters, but the extent to which these are damaged or can be powered over a global EMP is not known. It is worth noting that considerable research has been performed since the 1940s on optimising both gasification designs and methods for obtaining their fuel. So if that knowledge can be disseminated, then it would result in higher-performing, more efficient devices than those installed on Swedish cars in World War Two. The large uncertainty that surrounds this is the reason why a sensitivity analysis was completed both for the gasification rate and the delay period that occurs while information is disseminating.
2.2. Fuel Reserves

The immediate aftermath of a global EMP event will destroy much of the mining and refining equipment used in the fossil fuel supply chain. Thus, only open-pit coal, wood, and stockpiled fuels would be accessible enough to be used in the fuel supply chain.

2.2.1. Stockpiled Fuels

Diesel and gasoline reserves are typically stored in tanks and underground caverns above the upper explosive limit [20] meaning that even if the EMP event creates sparks in the vicinity of these tanks, there will not be enough oxygen to propagate the flame from the ignition source. Thus, it is expected that these reserves will remain intact.

The pumps and associated equipment required to access these reserves will likely be destroyed by the EMP event. It is assumed that siphons, bucket conveyors, or fossil-fuel-powered pumps will be able to access these reserves before a significant bottleneck occurs in the supply chain. Pumps may have to be manually controlled if their electronic control systems were damaged by the EMP.

Member countries of the Organization for Economic Co-operation and Development (OECD) have agreed to a number of energy reporting metrics from which global values of stored fuel can be estimated. The amount of above-ground stored diesel and gasoline in OECD countries is estimated to be $7.9 \times 10^{10} \pm 8.4 \times 10^9$ kg and $5.9 \times 10^{10} \pm 6.5 \times 10^9$ kg respectively [21]. OECD countries consume 46 ± 5% of global oil [22], which extrapolates to $1.7 \times 10^{11} \pm 2.9 \times 10^{10}$ kg of diesel and $1.3 \times 10^{11} \pm 2 \times 10^{10}$ kg of gasoline stored globally, assuming OECD storage patterns are a representative sample. These numbers are within 15% of the estimates obtained by Moersdorf et al. in 2023 and Denkenberger et al. in 2017 [9,23].

2.2.2. Wood

Global carbon in forests is $860 \times 10^{12} \pm 70 \times 10^{12}$ kg [24]; however, much of that is inaccessible in the soil, roots, and leaf litter. There are $363 \times 10^{12} \pm 28 \times 10^{12}$ kg of living biomass in forest, which have 24 ± 4% of their mass inaccessible in their roots [24]. The global amount of dead wood is $73 \times 10^{12} \pm 6 \times 10^{12}$ kg [24]. Thus, the total amount of global wood carbon available to harvest is $349 \times 10^{12} \pm 27 \times 10^{12}$ kg. This carbon is currently being harvested at a rate of $2 \times 10^{12} \pm 2 \times 10^{11}$ kg of wet wood each year [25]. Dry wood is 47 ± 5% carbon [26], and wet wood (freshly cut wood that has not dried out)
has a typical moisture content of $43 \pm 13\%$ [27]. This results in global wet wood reserves of $1035 \times 10^{12} \pm 382 \times 10^{12}$ kg.

Gasification devices convert wood into syngas with a $68 \pm 8\%$ conversion efficiency on a mass basis [18]. Thus, the world’s forests represent a potential stockpile of $700 \times 10^{12} \pm 270 \times 10^{12}$ kg of syngas and wood for $1.4 \times 10^{12} \pm 2 \times 10^{11}$ kg of syngas could be harvested daily at current harvesting rates.

2.2.3. Coal

Reserves of accessible coal are vast, at 1.1 trillion tonnes of economically extractable reserves [28]. Coal reserves will last another 133 years at current consumption [29]. Currently, 40% of global coal mining is open cut; it is possible but unknown that the large earth-moving vehicles used would be resistant to an EMP [30]. This percentage will decrease as more easily accessible sources are depleted, but it still represents a supply that could sustain civilisation during the recovery period after a global EMP.

Coal gasification has traditionally been used in industrial settings, and thus there is no precedent for the smaller-scale devices that vehicles require. Also, some historical cases exist of producing syngas at a centralised facility and then distributing it through the use of bags [31], but, in general, bags proved to be less viable than producing syngas from a gasification device located on the vehicle. There is potential for coal to supplement wood fuel in gasification devices installed on vehicles [32]. So while coal could be used to power stationary agricultural equipment such as irrigation pumps, its use is better suited to fuelling large mechanical power consumers where a bulky form factor is not an issue, such as industrial factories. So this paper will conservatively not consider using coal as a fuel source.

2.3. Fuel Demand

2.3.1. Food Production

Food production consumes $3.57 \times 10^6 \pm 5 \times 10^4$ TJ/year of energy obtained from diesel and $3.62 \times 10^5 \pm 5 \times 10^3$ TJ/year of energy obtained from gasoline [33]. When consumed, diesel releases $44.4 \pm 2$ MJ/kg and gasoline releases $45.4 \pm 1.6$ MJ/kg [34,35] resulting in the global consumption rate of agriculture being $8.04 \times 10^{10} \pm 3.8 \times 10^9$ kg of diesel/year and $7.97 \times 10^9 \pm 3.0 \times 10^8$ kg of gasoline/year.

Global agriculture had a collective installed mechanical power capacity of $3.13 \times 10^9 \pm 3 \times 10^6$ hp in 2021 to run tractors, harvester-threshers, milking machines, and water pumps, among other things [36]. This means 28 kg of liquid fuel is consumed per hp per year, which is a utilisation rate that is much lower than that for trucking. This utilisation rate could be increased by implementing nighttime operation, equipment sharing between farms, and installing a gasification device swap system. This difference in utilisation rate is the reason why trucks should be prioritised over farm equipment for gasification conversion.

Agriculture does not just consume mechanical energy from internal combustion engines; other large demands include electricity for irrigation pumps and natural gas heaters to dry out crops. However, this paper assumes that these demands will not compete with internal combustion engines for diesel or gasoline.

2.3.2. Food Transportation

Currently, global food freight amounts to $2.22 \times 10^{13} \pm 5 \times 10^{11}$ tkm/year, 71% of this freight is international with the rest being domestic. Ships move $93 \pm 6\%$ of international food freight, with the remainder being transported by trucks. Currently, $94 \pm 5\%$ of domestic food transportation is road haulage, with the remainder being rail and air freight [6].

Despite being the most fuel-efficient mode of transportation and experiencing decades of technological improvements to increase efficiency, ships emit 870 million tonnes of CO$_2$
annually, 2% of global greenhouse gases [37]. However, after a global EMP event, essential freight will be heavily prioritised reducing their fuel consumption.

A total of 49% of ships larger than 5000 gross tonnage are fueled by heavy oil fuel [38]. These ships easily have enough capacity to provide all international food transportation needs. Heavy oils are the bottom distillates obtained from the crude oil refining process. Because they are the bottom distillates, they can be obtained through the much simpler process of applying heat to crude oil to boil off lighter volatiles. These volatiles can be vented to the atmosphere, burned to provide heat for the process, or captured for refining after oil refineries come back online. However, condensing vapours requires considerably more capital than the process involved with boiling the crude. Most untapped oil fields are initially under positive pressure, which reduces as crude oil is removed. This positive pressure usually continues until 10 to 20 percent of their reserves are removed [39]. It is likely that these self-flowing oil wells will be able to provide the fuel for ships during the catastrophe recovery. For example, although the Saudi Ghawar oil field now uses active water injection to maintain positive pressure, it is likely that the oil field will still produce oil for the duration of the recovery [40]. Furthermore, the fuel requirement of ships can be reduced or completely replaced by next-generation wind technology, which uses paragliding sails [41,42], which plausibly could be produced in this loss of industry scenario.

Eating food grown domestically instead of importing food internationally does slightly reduce emissions relating to food transportation by 9% and food production-related emissions by 1.5% [6]. This reduction is due to the lower food transport ton kilometre, but the reduction is small because the bulk of the burden of this transport is moved from fuel efficient ships to inefficient trucks. However, this paper considers the scenario where ships do not compete with road transport for either diesel, gasoline, or wood gas. Thus, eliminating ocean freight would result in much higher consumption of those fuels by trucks, which is not considered. Furthermore, stopping international food freight is not viable since many regions are not self-sufficient in their food supply, there are annual regional variations, and the type of locally produced food might not provide a complete diet. This emphasizes the importance of maintaining international cooperation.

Air freight produces 10 times the emissions of road freight (0.82 kg of carbon dioxide per ton kilometer [43] compared to 0.081 kg of carbon dioxide per ton kilometre [44,45]). Thus, it will not be a justifiable mode of mass cargo transportation after a global catastrophe. Trains are particularly sensitive to EMPs because they have an electrical connection to the long steel rails, which will generate large currents. Trains that are not on the tracks when the EMP event occurs may be unscathed, but this is conservatively assumed to be an insignificant proportion of global transport infrastructure. Trucks can also be repurposed to run on train tracks and thus operate more efficiently. However, due to the complexity of that retrofit, this transportation is not considered in this paper. Barges are large and therefore would have large currents induced. Thus, trucks are the only land transport modality considered.

Heavy trucks have a typical horsepower of 500 ± 100 hp [46] and a cargo capacity of 20 tons [47] from which the additional weight of the gasification devices and wood fuel (5000 kg) need to be subtracted. Their most fuel-efficient speed operating with diesel fuel is 60 ± 10 km/h [48]. Depending on local regulations, they typically operate between 8 and 10 hours a day. However, during a crisis, these regulations will likely be lifted, and these trucks will be operated continuously, perhaps to 20 ± 2 h a day, with the only downtime being for loading and unloading cargo and fuel, conducting maintenance, and swapping drivers, resulting in a utilisation rate of 83 ± 8%. Syngas is not as energy dense as diesel or gasoline, which results in a power loss of 17 ± 3% during use [49]. Also, only 80% of the diesel fuel on a mass basis can be replaced with syngas [49]. Thus, the typical heavy truck with a gasification device during a crisis is likely to be able to transport $3.76 \times 10^4 ± 9.4 \times 10^3$ tkm/day, which equates to $293 ± 150$ kg of diesel/(truck × day) and $1170 ± 586$ kg of syngas/(truck × day); this is in comparison to the $1210 ± 492$ kg of diesel/(truck × day) fuel consumption of a truck without a gasification device installed.
Installing a gasification device on a truck reduces its cargo carrying capacity by approximately 20%.

The truck load limit used in the calculation above is the amount allowed by regulations in most countries. It is possible to greatly exceed this load limit, with an outlier being the truck road trains in Australia, which can have a total mass exceeding 200 tons [50]. However, if this limit is exceeded during a crisis, then routes must be carefully chosen to avoid overloading sensitive road infrastructure such as bridges, and the truck’s superstructure and breaking system might have to be improved. This is conservatively not considered in the model.

2.3.3. Rationing

The world currently produces 210% of the food calories needed to feed everyone adequately [23]. On top of this oversupply, there are considerable opportunities to reduce food losses in the supply chain and increase the efficiency of food production during an emergency.

There are a number of ways food losses can be minimised. In 2018, the global average of food delivered daily per person to their house was 2930 kilocalories (kcal) [51]. However, the recommended daily calorie intake is 2080 kcal [52], which suggests that food could be reduced by 30% and still provide the macronutrient energy content. A total of 2080 kcal is the optimum daily intake; this amount can be temporarily reduced. Furthermore, tragically, events correlated with a global EMP, such as a nuclear war, will significantly reduce the global population who will no longer need food. It should also be noted that a global EMP will damage warehousing logistics and refrigeration systems [1], which could result in more food loss in the supply chain.

Global consumption of meat is 360 million tonnes, and 37% of cropland is dedicated to feeding these animals; that is food that people could be eating instead [53]. Furthermore, pasture land for raising animals accounts for 70% of all farm land [54]. Pasture land tends to be less valuable land, which would obtain lower yields than typical crop land but still most likely higher yields than from cattle. Technology like leaf protein concentrate can convert the grass from these pasture lands into human edible protein [55]. Although the factories required to do this at an industrial scale will likely be damaged by the global EMP, leaf protein concentrate can also be made at the household scale [56].

Chickens and pigs are able to put on one kilogram of wet weight for every two kilograms of dry feed consumed; for cows, the ratio is one to five [57]. Chickens and pigs generally consume human edible food, so they are directly competing with us for food. Furthermore, meat supply chains require more energy-intensive refrigerated transport and more complex processing facilities, making them more susceptible to global catastrophic infrastructure losses. If farmland was no longer used to raise animals, there would be significantly less farming infrastructure required to grow food. Replacing low-nutrition crops like coffee beans, strawberries, and lettuce with highly productive crops like soy beans, wheat, and maize would also have a similar effect.

2.4. Converting Diesel Engines

Diesel engines rely on the self-ignition properties of the diesel fuel to initiate fuel burn. However, syngas from wood gasification requires spark plug ignition. It is possible to install spark plugs through the fuel injector slot, but engines are not designed for this. Diesel engines also have a compression ratio that is too high. This can be reduced by a combination of installing thicker head gaskets and milling material off of the piston heads.

Another way to convert diesel trucks is to replace the entire engine with a gasoline engine and mate it with the drive shaft. Gasoline utility vehicles have the horsepower required to pull railway cars or semi trailers at moderate and low speeds, respectively; however, both of these solutions require non-trival retrofitting using machinery that is likely to be destroyed by the catastrophe. All of these adaptations are complex, slow, expensive, and uncertain,
so they are conservatively not modelled. However, it is important that either these diesel engines are converted or diesel fuel production is restored before diesel reserves run out.

2.5. The Main Scenario

A main scenario that incorporates a set of plausible interventions has been developed from the factors discussed in the preceding sections. This scenario will be used to determine the relative importance of different policy interventions.

The main scenario converts trucks to run on syngas before agricultural equipment since this results in significantly longer stockpile duration. The truck utilisation is assumed to be increased to 20 ± 2 h/day, and agricultural equipment utilisation is doubled. Initial reserves are set at current reserve quantities, and a linear gasification rate of $8.3 \times 10^6$ hp/day is assumed with an initial six-month delay. Food production is also reduced by 25% of current values to model rationing.

The main scenario is compared to the operation as usual scenario. For operation as usual, no equipment has gasification devices installed, food production continues at current rates, the utilisation rate of equipment is not changed, and the current reserves of fuel are used.

2.6. Statistical Analysis

To estimate fuel reserves in different scenarios, a general mass balance was performed. It is assumed that global catastrophic infrastructure loss destroyed the ability to mine and refine fuel, so the input into the mass balance is zero. The fuel accumulated starts as the initial fuel reserves, which reduce as they are used up. The output of the mass balance is broken into two parts: the fuel consumed for the production of food and the fuel consumed for the transportation of food. In all gasification device scenarios, the optimum strategy was to convert the transportation industry before the production industry due to its much higher vehicle utilisation rate.

For each time interval, the instantaneous consumption of fuel by food production and transportation is calculated separately and then subtracted from the fuel stockpile calculated in the previous loop iteration. The instantaneous consumption was obtained from the derivative of the mass balance and also takes into account how many vehicles have gasification devices installed on them. There are four phases in the model: first, no gasification devices are installed as information is being distributed; second, gasification devices are installed on trucks; third, all trucks are now converted and gasification devices are installed on tractors; and fourth, all trucks and tractors have been converted. This results in four piece-wise functions that connect seamlessly in the plot but have different curvatures. The various sensitivity plots were created by varying the respective input parameter and repeating the program.

The Python script reads in all of the 120 input parameters and their associated 90th percentile uncertainties from a spreadsheet that contains references for every input parameter to allow for transparent traceability. Both the code and the spreadsheet are available in the Supplementary Materials. To calculate the uncertainties in all the outputs of the model, each of the input parameters were randomly sampled from a normal distribution centered around the parameter’s mean value, with standard deviation calculated from the 90th percentile of that parameter. The model is then run for that sampling of parameters, and all the model’s outputs are recorded. This was repeated 5000 times, and the output’s uncertainty was calculated from that sample.

3. Results

Figure 2 shows the results of the general mass balance for diesel, comparing the main scenario with operation as usual. This mass balance relates the effect that inputs and outputs have on the amount stockpiled.
Figure 2. Comparing the main scenario with its uncertainty against the scenario where no gasification devices are installed.

The plot in Figure 2 consists of four regimes connected in a piece-wise fashion. The first regime is the delay period, where information about optimal gasification designs is being disseminated for the main scenario; this ends after 60 days. It is followed by the phase of installing gasification devices on trucks, which is achieved 106 days after the global catastrophe. After all trucks have been converted, agricultural equipment is then converted, which takes until day 389 because of their low utilisation rate.

The global catastrophic infrastructure loss will disable oil refinery production, so inputs into the stockpiles of diesel and gasoline will cease. However, wood harvesting equipment is resilient to the effects of an EMP and will be able to continue adding to the amount of wood that is stockpiled.

Diesel, gasoline, and wood are consumed in a variety of ways; however, only uses relevant to the production and distribution of food are considered here. Due to their higher utilisation rate, trucks are converted before agricultural equipment. Heavy trucks almost exclusively use diesel, and thus diesel consumption starts to be reduced as soon as gasification devices are installed. However, due to the higher compression ratio and a lack of a spark plug, diesel engines still need to consume at least 25 ± 5% diesel, so diesel reserves continue to decline even after all these pieces of equipment have been converted. Gasoline has a longer delay period since agricultural equipment that uses gasoline is converted later; however, gasoline consumption can be completely replaced by syngas. Wood consumption is proportional to the number of gasification devices installed and their utilisation rate.

It was found that if vehicles are not installed with gasification devices, diesel fuel reserves would last between 158 days and 481 days with 80% confidence, whereas the mean is 195 days. However, the main scenario increased stockpile duration to last between 382 days and 1501 days with 80% confidence, whereas the mean is 757 days. As can be seen in Figure 2, the average of the main scenario outperforms operation as usual (no gasification) by 562 days for diesel stockpile duration. Furthermore, industry is able to fully substitute gasoline with syngas consumption well before stockpiles are depleted. When all gasification devices have been installed, the wood consumption is $5.2 \times 10^9$ kilograms of wet wood per year, which is less than 1% of the current wood production rate. This means that diesel is the bottleneck of all scenarios.
The Monte Carlo analysis shown as the shaded area in Figure 2 demonstrates how the error propagation increases as the model progresses. Initial uncertainty is largely caused by uncertainty in the initial reserve of fuel, but as more gasification devices are installed, other sources of uncertainty become more prominent. Monte Carlo analysis using 5000 samples was used to propagate uncertainties throughout the equations to obtain bounds for all the parameters described in this report. Monte Carlo analysis using 10000 simulations was run to obtain the bounded areas shown in Figure 2.

The food production sensitivity analysis shown in Figure 3 reveals the most important controllable parameter of the model. Reducing food consumption by 50% resulted in an 80% longer fuel reserve duration over the main scenario, which already had a 25% food reduction. There is a non-linear relationship between food production and diesel reserve duration. This is because not only is all relevant equipment getting installed with gasification devices earlier, but there is also less consumption of diesel due to fewer crops needing to be produced. Thus, installing gasification devices has a larger impact when less food is being produced.

![Figure 3. A sensitivity analysis demonstrating the effect of varying the food consumption on the diesel reserves.](image)

A sensitivity analysis was performed on both the delay period (Figure 4) and the rate of gasification device installation (Figure 5). Both factors were determined to significantly impact the diesel reserve duration. The delay period is affected by the time to develop and disseminate the design of gasification devices and will be dependent on the prevalence of long-distance communication, the presence of centralised coordination, and the amount of preparation, before the global catastrophic infrastructure loss. The World War Two Sweden case study demonstrates that with adequate preparation this delay period can be reduced to zero. The rate at which gasification devices are installed is another important factor, which is influenced by what equipment is available and the skill and learning proficiency of the workers. Interestingly, the delay period is a more important parameter to optimise than the gasification rate. In fact, doubling the rate per capita that the Swedes managed to install gasification devices at only results in an 11% increase in diesel reserve duration. But reducing the delay from 60 days to 0 days increased the diesel reserve duration by 27%.
Figure 4. A sensitivity analysis demonstrating the effect of varying the initial delay period on the diesel reserves.

Figure 5. A sensitivity analysis demonstrating the effect of varying the rate at which gasification devices are installed on the diesel reserves.

Figure 6 shows that increasing the utilisation rate of agricultural equipment such as tractors has some benefit but is the least effective strategy. There are minimal gains made after the equipment’s utilisation rate has doubled, which could easily happen with equipment sharing between farms or nighttime usage. Further effort to increase this utilisation would likely not be as effective as directing that effort elsewhere.
Figure 6. A sensitivity analysis demonstrating the effect of varying the utilisation rate of agricultural equipment on the diesel reserves.

4. Conclusions

It was successfully shown that a novel group of interventions all had large effects on extending the duration, which we can grow and distribute food using fossil fuels after a global catastrophic infrastructure loss event. A reasonable combination of these interventions increased that duration by a factor of 3.9. Out of these interventions, reducing food consumption had the strongest effect followed, by minimising the time delay before gasification devices are installed, increasing the rate at which those devices are installed, and increasing the agricultural equipment utilisation rate. In all scenarios, diesel was the limiting fuel, and future work is recommended to model retrofitting diesel engines in a no-industry scenario to run completely on wood gas. This analysis was performed on a global level, assuming international trade; however, regional analysis is recommended to identify the countries that are least resilient to this kind of infrastructure loss. Continued research will play a pivotal role in increasing the resiliency of the global food supply chain, enabling everyone to be fed no matter what.

Supplementary Materials: The spreadsheet and Python scripts that describe the model and are used to generate the plots can be downloaded at: https://github.com/DavidChristopherNelson/wood_gasification_paper/tree/main, accessed on 21 February 2024.

Author Contributions: Conceptualization, A.T. and D.D.; methodology, D.N.; software, D.N.; validation, D.N., A.T. and D.D.; formal analysis, D.N.; investigation, D.N. and A.T.; resources, D.N.; data curation, D.N.; writing—original draft preparation, D.N.; writing—review and editing, D.N., A.T. and D.D.; visualization, D.N.; supervision, D.D.; project administration, D.D.; funding acquisition, D.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Acknowledgments: The authors would like to thank Mengyu Li for her assistance in interpreting multi-regional input output data related to the global production and transportation of food.

Conflicts of Interest: The authors declare no conflicts of interest.
References


13. Norris, R.S. Global Nuclear Stockpiles, 1945–2006. [CrossRef]


40. Stenger, B.; Pham, T.; Al-Afaleg, N.; Lawrence, P. Tilted Original Oil/Water Contact in the Arab-D Reservoir, Ghawar Field, Saudi Arabia. GeoArabia 2003, 8, 9–42. [CrossRef]


43. Howitt, O.J.A.; Carruthers, M.A.; Smith, I.J.; Rodger, C.J. Carbon Dioxide Emissions from International Air Freight. Atmos. Environ. 2011, 45, 7036–7045. [CrossRef]


52. UNHCR; UNICEF; WFP; WHO. Food and Nutrition Needs in Emergencies; Geneva, Switzerland; New York, NY, USA; Rome, Italy, 2002.

53. Manceron, S.; Ben-Ari, T.; Dumas, P. Feeding proteins to livestock: Global land use and food vs. feed competition. OCL 2014, 21, D408. [CrossRef]


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