Global industrial disruption following nuclear war

Simon Blouin[1,*], Florian U. Jehn[1] and David C. Denkenberger[2]

[1] *Alliance to Feed the Earth in Disasters, Lafayette, CO 80026, USA*
[2] *University of Canterbury, Christchurch 8041, New Zealand*

[*] Corresponding author: Simon Blouin, simon.b@allfed.info

Abstract

Nuclear war poses catastrophic risks not only through its immediate effects and potential nuclear winter, but also through the disruption of industrial production on which modern civilization depends. We first derive a nuclear weapon destruction radius scaling relationship from historical data and fire modelling and combine it with OpenStreetMap industrial facility locations to calculate direct infrastructure losses. We then quantify supply-chain amplification by fitting a power-law relationship between infrastructure loss and output decline across seven historical disruptions. In an India–Pakistan exchange where each side strikes the other's urban centres with 85 warheads of 15 kilotons, we estimate reductions of approximately 5% and 22% of India's and Pakistan's national industrial outputs. We also modelled a US–Russia scenario where Russia strikes the United States with 2,030 warheads of 100–800 kilotons following an open-source target list. We assume proportionally similar damage for Russia. National industrial output reductions reach approximately 58% in each country, which, combined with trade-mediated spillovers, implies a global industrial output decline of at least 20%. Financial contagion, high-altitude electromagnetic pulse attacks and escalation to other NATO states would push the disruption substantially higher. Such industrial collapse would severely impair humanity's ability to meet basic needs and adapt to nuclear winter.

Keywords: global catastrophic risk, industry, nuclear war, critical infrastructure, supply chains

1 Introduction

A large-scale nuclear war would cause unprecedented destruction, with immediate casualties numbering in the tens or hundreds of millions (Batcher, 2004; Toon, Robock and Turco, 2008; Philippe and Stepanov, 2023). However, the greatest threats to the continued existence of modern human civilization lie not in the direct effects of the explosions, but in their long-term, global consequences (Toon, Robock and Turco, 2008; Baum, 2015; Scouras, 2019). Nuclear winter—where stratospheric soot from urban firestorms could reduce sunlight and agricultural productivity for years—represents a major risk that has received significant research attention (Toon, Robock and Turco, 2008; Coupe et al., 2019; Wagman et al., 2020; Xia et al., 2022; Rivers et al., 2024; NASEM, 2025). Another critical yet understudied risk of nuclear conflict is Global Catastrophic Infrastructure Loss (GCIL), a scenario characterized by widespread failure or destruction of critical infrastructure systems worldwide, severely impairing society's ability to produce and distribute essential goods and services (Moersdorf et al., 2024).

Historical evidence from previous conflicts suggests that in a nuclear war, critical industrial infrastructure such as ports and oil refineries would likely be targeted (Richard, 2017). Even if not directly targeted, a portion of this vital infrastructure could be destroyed as collateral damage from attacks on nearby urban centres. The loss of these industrial assets could severely impair humanity's ability to meet its basic needs (Abdelkhaliq et al., 2016; Denkenberger et al., 2021). In particular, modern agriculture is heavily reliant on industrial inputs such as fuel, fertilizers and pesticides (Ahvo et al., 2023; Moersdorf et al., 2024), meaning that a decrease in industrial capacity would exacerbate the agricultural challenges posed by nuclear winter (Denkenberger et al., 2017). Beyond agricultural production, the entire food supply chain also depends on functional industrial infrastructure (Blouin et al., 2024).

Modern industry relies on complex supply chains where the output of each facility depends on inputs from numerous others. Through these linkages, shocks to one industry or region can propagate throughout the economy (Acemoglu et al., 2012; Hallegatte, 2014; Barrot and Sauvagnat, 2016; Inoue and Todo, 2019; Carvalho et al., 2021), and these ripple effects can extend far beyond national borders through international supply chains (Schulte In Den Bäumen et al., 2014; Inoue and Todo, 2022; Kang, Lee and Yang, 2024; Meier and Pinto, 2024). Moreover, these disruptions are amplified as they spread, as the loss of one input can halt production that depends on it (Baqaee and Farhi, 2019). These interdependencies imply that the impact of nuclear war on industrial production could extend well beyond the directly damaged areas.

The economic consequences of nuclear attack were studied during the Cold War (Winter, 1963; Katz, 1982). Here we revisit this question using scenarios more representative of current arsenals, combining modern geospatial data with additional decades of historical evidence on industrial disruption. We proceed in two stages. First, we estimate direct infrastructure damage by developing a nuclear weapon destruction radius scaling relationship and combining it with OpenStreetMap industrial facility locations. Second, we fit an empirical relationship across historical disruption events to estimate how such localized infrastructure losses propagate through supply chains. We apply this framework to assess both an India–Pakistan nuclear exchange and a full-scale US–Russia nuclear war.

2 Damage Estimation Methodology

2.1 Nuclear weapons effects on infrastructure

The atomic bombings of Hiroshima and Nagasaki remain the most reliable reference points for understanding the destructive capacity of nuclear detonations. In Hiroshima, a 15 kiloton (kt) weapon destroyed 13 km² of the city, while in Nagasaki, a 21 kt weapon destroyed 6.7 km² (The Committee for the Compilation of Materials on Damage Caused by the Atomic Bomb, 1981; Malik, 1985). In both cases, the buildings completely destroyed by blast alone (without fire) represented less than 10% of all the completely destroyed buildings, making the burn region a good approximation of the overall destruction zone (The Committee for the Compilation of Materials on Damage Caused by the Atomic Bomb, 1981). To estimate the effects of modern nuclear weapons, which typically have yields Y in the hundreds of kt, we need to scale up from these historical data points.

Any such extrapolation carries substantial uncertainty. Consider first the scaling with yield. Some nuclear winter studies have assumed that the burn radius scales as $R \propto Y^{1/2}$ (Toon, Robock and Turco, 2008), following the scaling for thermal radiation without atmospheric attenuation. However, this likely overestimates damage from high-yield weapons for two reasons. First, the atmosphere reduces thermal radiation range (Glasstone and Dolan, 1977). Second, many fires result from blast damage (e.g., ruptured gas lines; The Manhattan Engineer District, 1946), and blast effects scale more slowly with yield ($R \propto Y^{1/3}$; Glasstone and Dolan, 1977). These two exponents (1/3 and 1/2) thus bracket the physically plausible range.

Furthermore, the two available anchor points are inconsistent. Hiroshima's 15 kt weapon destroyed nearly twice the area of Nagasaki's 21 kt weapon, reflecting terrain confinement and the absence of a firestorm in Nagasaki. Whether present-day urban areas would generate Hiroshima-like firestorms is contested (Reisner et al., 2018, 2019; Robock, Toon and Bardeen, 2019).

To take these uncertainties into account, in what follows we re-run our entire targeting pipeline under four bounding cases spanning both axes of this uncertainty: each of the two exponents anchored, in turn, at Hiroshima and at Nagasaki. We adopt as our fiducial choice a power-law fit that combines the Hiroshima and Nagasaki data with modelled burn areas from higher-yield detonations (50 kt and 1 Mt) that account for both thermal and blast-induced fires (Brode and Small, 1984). Fitting by ordinary least squares in log–log space yields a best-fit power law scaling of $R = 0.57 \times Y^{0.43}$, where R is the radius of the area destroyed in km and Y is the yield in kt (Figure 1). This intermediate exponent reflects the combined effects of blast damage, thermal radiation, and atmospheric attenuation. Given that the burn area closely approximates the total destroyed area in Hiroshima and Nagasaki, and that burn area scales more rapidly with yield than blast effects, the burn area should be an even better approximation of total destruction for modern higher-yield weapons.

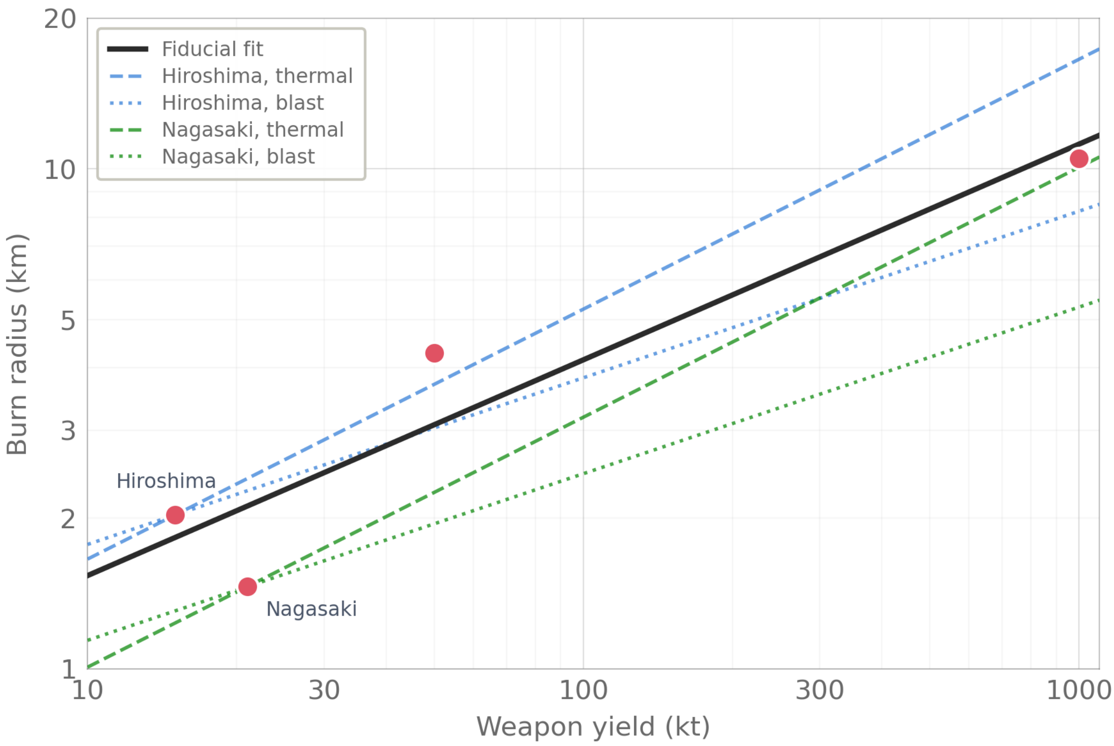

Figure 1: Scaling relationships between nuclear weapon yield and burn radius. Red dots represent empirical and modelled data points: two from the atomic bombings of Japan (15 kt and 21 kt) and two from the modelling of 50 kt and 1 Mt detonations (Brode and Small, 1984). The solid line shows our best-fit power law scaling ($R = 0.57 \times Y^{0.43}$). The other four curves are the bounding cases of the sensitivity analysis: the ideal thermal radiation scaling ($R \propto Y^{1/2}$, dashed lines) and the blast damage scaling ($R \propto Y^{1/3}$, dotted lines), each anchored at Hiroshima (blue) and at Nagasaki (green). The near-factor-of-two difference in destroyed area between Hiroshima and Nagasaki illustrates the irreducible case-to-case variability. We extracted the high-yield data points from Brode and Small (1984), taking the distances from ground zero where the fire damage probability reaches 50% in their mean damage model. We assume 100% destruction within this radius as a simplifying approximation that compensates for neglecting partial damage beyond it.

We derived this scaling relation from air-burst detonations, which we expect to account for most industrial destruction in a nuclear conflict. Ground bursts are likely to be reserved primarily for strikes against hardened military assets, where their ability to transmit more blast energy to their targets outweighs their smaller overall destruction radius. Note that air bursts generally produce relatively little radioactive contamination (Glasstone and Dolan, 1977), as evidenced by the fact that Hiroshima and Nagasaki were continuously inhabited. Therefore, radioactive fallout from air bursts is unlikely to significantly impact industrial activities beyond the immediate destruction zone, and we neglected this effect in this work.

2.2 Industrial infrastructure assessment

We used OpenStreetMap (OSM) data (Haklay and Weber, 2008; OpenStreetMap contributors, 2024) to identify industrial assets and estimate infrastructure losses from nuclear detonations. We extracted polygons tagged with `landuse=industrial`, which encompasses factories, warehouses, and other land designated for industrial purposes. For each simulated detonation (Section 4), we calculate the overlap between its destruction radius and industrial areas (Figure 2), allowing us to estimate the fraction of industrial infrastructure destroyed in different scenarios.

Figure 2: Example application of industrial damage assessment methodology. The red circle represents the predicted destruction radius for a 300 kt detonation over the Port of Rotterdam. Industrial zones from OpenStreetMap are shown as polygons, with hatched areas indicating zones considered destroyed based on their intersection with the destruction radius.

To estimate the fraction of a country's industrial capital lost in a given scenario, we computed the ratio of destroyed industrial polygon area to total industrial polygon area within that country. While this area-based weighting approach has limitations in capturing variations in industrial output density, it provides a reasonable first-order approximation, supported by the strong correlation between industrial land area and economic output observed in regional analyses (Silva et al., 2014). However, manual inspection revealed that the largest polygons with areas surpassing 10 km^2 typically represent low-capital facilities like quarries and proving grounds. To avoid overweighting these outliers, we ignored industrial areas larger than 10 km^2.

To validate OSM data quality, we conducted two separate tests. First, we evaluated coverage by focusing on oil refineries and fertilizer/pesticide manufacturing facilities in the United States, India, and Pakistan. We compiled reference datasets of 157 oil refineries (127 in US, 23 in India, 7 in Pakistan) and 65 fertilizer/pesticide facilities (37 in US, 25 in India, 3 in Pakistan). Of these facilities, 99% of refineries and 95% of fertilizer/pesticide plants were correctly tagged as industrial zones in OSM data. Second, we assessed classification correctness by randomly selecting 120 OSM industrial polygons (40 per country) using area-weighted sampling. Visual inspection of satellite imagery confirmed that 94% (113/120) of these polygons contained industrial facilities. Given the high coverage of critical industrial facilities and low commission error rates, we deemed OSM data sufficiently reliable for estimating industrial infrastructure losses.

Our analysis was implemented in Python using geospatial libraries (Jordahl et al., 2020) to process industrial infrastructure data and calculate destruction patterns. The code processes lists of detonation coordinates and yields and calculates the resulting industrial destruction for each target location based on the burn radius scaling derived previously.

3 Historical Patterns of Industrial Disruption

To estimate how direct infrastructure losses propagate through supply chains into total industrial output, we assembled historical events for which both the fraction of national industrial infrastructure incapacitated (x) and the resulting peak decline in national industrial production (y) can be estimated from published sources. Here, x counts industrial capital unavailable to the national economy at the time of peak disruption (i.e., destroyed, severely damaged, or located in occupied or isolated territory). The output variable y is the total peak decline in national industrial production, including all disaster- or war-concomitant channels (e.g., power shortages, labour displacement, trade interruption, financial shocks), on the argument that similar compounding effects would also accompany nuclear war. Cases were included if (i) both x and y are estimable from published quantitative sources; (ii) the event occurred in an industrialized economy; and (iii) the shock was national in scale. Using these criteria, we identified seven cases:

- **2005 hurricanes Katrina and Rita:** In 2004, Louisiana and Mississippi respectively accounted for 1.1% and 0.2% of total US industrial activity (Federal Reserve Bank of St. Louis, 2004). To estimate the fraction of industrial infrastructure disabled, we use housing damage as a proxy: 19% of Louisiana's housing stock and 11% of Mississippi's were destroyed or severely damaged (FEMA, 2006), suggesting similar levels of industrial infrastructure damage. Weighting these destruction rates by each state's share of national industrial GDP yields approximately 0.23% loss of US industrial infrastructure. The Federal Reserve estimates that storm-related declines held down total US industrial production by about 1.7 percentage points in September 2005 (Federal Reserve, 2005).

- **1995 Kobe earthquake:** In Hyōgo prefecture, 240,956 buildings fully or partially collapsed (Hyōgo Prefecture, 2006), corresponding to 11.9% of the prefecture's 2,019,000 dwellings recorded in the 1993 Housing Survey (Statistics Bureau of Japan, 2012). Hyōgo accounted for 4.86% of national manufacturing shipments in 1994 (Statistics Bureau of Japan, 2012), yielding an estimated 0.6% loss of Japan's industrial infrastructure. National industrial production fell by 2.6% in January 1995 (Curley, 2011).

- **2011 Tōhoku earthquake:** Nationwide, 405,166 buildings were fully or half destroyed (Fire and Disaster Management Agency, 2022), corresponding to 0.7% of Japan's dwellings (Statistics Bureau of Japan, 2012). We take this as a proxy for the damage rate to manufacturing capital. The earthquake and tsunami also knocked 33 GW of power plants offline (Institute of Energy Economics Japan, 2011), which corresponded to 11.7% of Japan's generating capacity (US Energy Information Administration, 2012). Weighting the two components by their shares of Japan's industrial GDP (89.6% manufacturing and mining, 10.4% utilities; Cabinet Office, 2012) yields approximately 1.8% of industrial infrastructure incapacitated. National industrial production fell by 15% in March 2011 (European Central Bank, 2011).

- **2022 Russian invasion of Ukraine:** Ukraine's industrial sectors (extraction, food processing, steel, other manufacturing, and power) lost productive capacity equivalent to 3.5 percentage points of the country's total economy-wide capacity between February and September 2022 (counting assets destroyed, damaged, or located in occupied territory; Djankov and Blinov, 2022). As these sectors constituted 22.2% of Ukraine's pre-war GDP, this corresponds to approximately 16% of Ukraine's industrial capacity incapacitated. Industrial production fell by 37% that same year (United Nations Economic Commission for Europe, 2024).

- **1941 German invasion of the USSR:** Within six months of the invasion, German forces occupied or isolated territory containing one-third of the fixed capital assets of the Soviet state enterprise sector (Linz, 1984). Gross industrial output dropped by 52% between June and November 1941 (Voznesensky, 1948).

- **WWII bombing of Germany:** By the end of World War II, Allied bombing had destroyed 17% of German industrial capital (Plumpe, 2016). The British Bombing Survey Unit found a 48% loss in overall armaments production, 59% in aircraft production, and 42% in tank production in 1945 (Overy, 2001). Taking these figures as representative, we estimated a 50% reduction in total industrial output.

- **WWII bombing of Japan:** US bombing during World War II destroyed 34% of Japan's industrial machinery and equipment (Kōsai and Goble, 1989). In 1946, industrial production had fallen by 72% compared to prewar levels (Nakayama, 1963).

Because y measures the peak decline, it gives no information about how long that decline lasts. Here, the decline duration differs sharply between the seven cases, but a nuclear war aftermath would resemble the wartime points, and could be considerably worse for large-scale nuclear exchanges given the potential for nuclear winter, electromagnetic-pulse damage, and the absence of outside aid. We therefore read our estimates as applying to at least the first year after the exchange.

To quantify the relationship, we fit a power law $y = a \cdot x^b$ by ordinary least squares in log–log space through the seven data points, with uncertainty quantified by a case-resampling bootstrap (10,000 draws). The fit gives $b = 0.73$ (90% CI: 0.48–0.81) and $a = 5.4$ (90% CI: 4.2–11.5) (Figure 3). Because $b < 1$, the amplification factor y/x falls as the shock grows. As an independent check, a 1974 study of the consequences of nuclear attacks on US industry concluded that a 10% loss in the production capacity of basic sectors would reduce the output of defence-related industries by 30–40% (Katz, 1982). At a 10% loss, our relationship predicts a 29% decline (90% CI: 25–36%), consistent with the study's estimate. Including this point in the fit would leave all predictions essentially unchanged.

4 Scenario Analysis

4.1 India–Pakistan nuclear war

Pakistan and India possess approximately 170 nuclear warheads each, primarily in the 5–40 kt range (Kristensen, Korda and Johns, 2023; Kristensen et al., 2024a). We modelled a scenario where each nation uses 50% of its arsenal against the other's population centres, with 15 kt warheads (Toon et al., 2019). This urban targeting assumption aligns with both nations' nuclear doctrines, which include countervalue elements targeting population centres (Tasleem, 2016; Clary and Narang, 2019). While the 50% usage rate is speculative, it aims to account for weapons that would fail to reach their targets, be used against military targets typically located away from industrial zones, or be held in strategic reserve (particularly relevant for India given its deterrence posture toward China; Kurita, 2018). The remaining weapons were excluded from our industrial damage calculations.

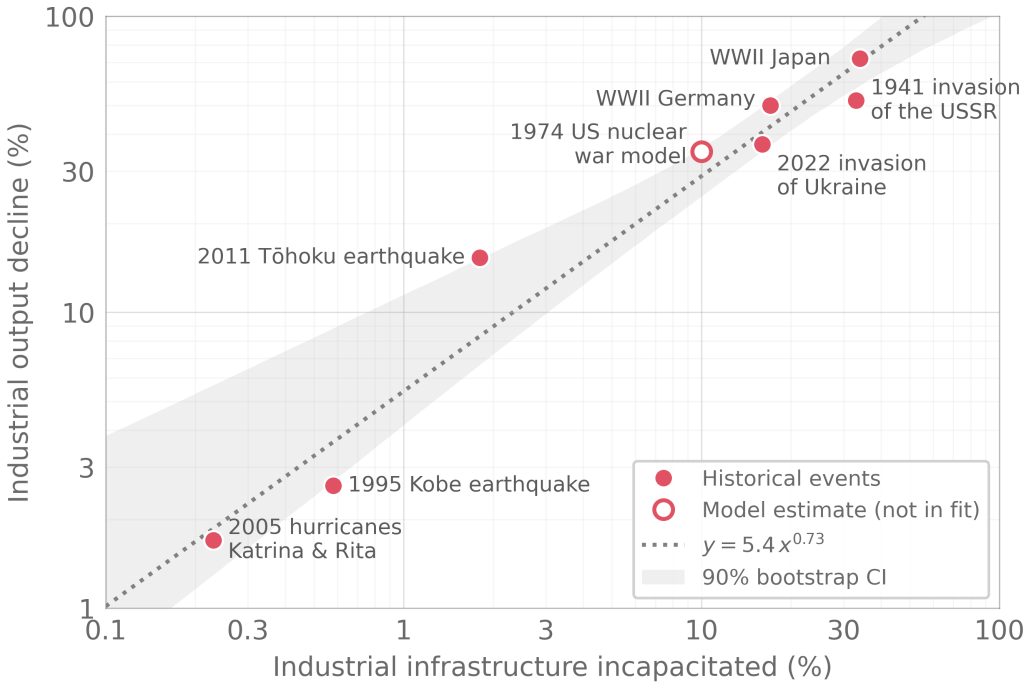

Figure 3: Relationship between the share of national industrial infrastructure incapacitated and the peak decline in national industrial output across seven historical events. The dotted line shows the power-law fit $y = 5.4 \cdot x^{0.73}$, and the shaded band its 90% confidence interval from a case-resampling bootstrap (10,000 draws). The open marker denotes the model-based estimate of a 1974 US nuclear war study (Katz, 1982), which is excluded from the fit and shown only as an independent check. All cases involve compounding factors beyond direct infrastructure loss, such as transportation disruptions, power shortages, labour displacement, and financial shocks, which are conditions likely to accompany nuclear conflict as well.

Using LandScan 2022 population density data (Sims et al., 2022), we simulated the detonation of 85 warheads from each side, selecting target locations iteratively to maximize additional casualties. Our casualty estimation methodology follows Toon et al. (2007) and yields 57 million immediate fatalities, consistent with their later assessment of an India–Pakistan exchange (Toon et al., 2019). This nuclear exchange would destroy 0.9% and 7.0% of the industrial capital of India and Pakistan, respectively. Under the bounding burn-radius cases of Section 2.1, these figures range over 0.5–1.4% for India and 3.2–7.6% for Pakistan, bracketing the fiducial values.

For India's 0.9% industrial infrastructure loss, our fitted relationship (Figure 3) predicts a 5% reduction in national industrial output (90% interval: 4–11%). This places India's predicted experience between Japan's 1995 Kobe earthquake (2.6% decline after a 0.6% loss) and the 2011 Tōhoku earthquake (15% decline after a 1.8% loss). For Pakistan's 7.0% infrastructure loss, the relationship predicts a 22% reduction (90% interval: 19–29%). Allowing additionally for the burn-radius bounding cases of Section 2.1 widens these intervals to 2–13% for India and 10–31% for Pakistan.

4.2 US–Russia nuclear war

We analyse a full-scale nuclear exchange between the United States and Russia using the counterforce+countervalue target list from OPEN-RISOP, a compilation of hypothetical Russian nuclear strike targets in the United States (Teter, 2022). This scenario employs 2,030 warheads—a plausible number given Russia's estimated arsenal of 2,822 strategic nuclear warheads, including 1,710 deployed (Kristensen et al., 2024b). All 450 US intercontinental ballistic missile silos are targeted with 800 kt ground bursts. Most remaining targets receive warheads ranging from 100 to 250 kt. The target list encompasses military installations (e.g., 118 military airfields, 107 military bases, 45 missile launch control centres), critical infrastructure (e.g., 74 oil refineries, 47 dams, 29 cable landing stations), and civilian/government targets (e.g., 131 city halls, 32 state capitols).

We estimated 57 million immediate fatalities in the United States from prompt radiation, blast and fires. Fallout from ground bursts against missile silos would cause additional deaths (Office of Technology Assessment, 1979; Daugherty, Levi and Von Hippel, 1986; Philippe, 2023). Our analysis indicates that 26% of US industrial infrastructure would be destroyed (14–32% under the bounding burn-radius cases of Section 2.1). For Russian losses, lacking a comparable target map, we assume proportionally similar destruction. While Russia's more concentrated industrial geography may suggest higher destruction percentages, the US would likely reserve a significant number of warheads to deter other adversaries.

Based on our fitted relationship (Figure 3), a 26% loss of industrial infrastructure predicts a reduction in national industrial output of approximately 58% for each country (90% interval: 49–70%); propagating the burn-radius bounding cases (14–32% of infrastructure destroyed) through the central fit gives output declines of roughly 37–67%. Allowing for both sources of uncertainty simultaneously gives a combined range of 32–83%. This is directly comparable to the historical record at similar infrastructure losses: Germany's industrial output fell by about 50% after 17% of its industrial capital was destroyed in WWII, and Soviet industrial output fell by 52% after one-third of its industrial capital was occupied or isolated in 1941.

4.3 Additional risk factors

Several mechanisms could amplify the industrial infrastructure loss beyond the direct blast and fire damage considered above. Some targets might be selected specifically for their potential to cause widespread collateral effects. For instance, strikes on major dams could trigger catastrophic flooding of industrial zones, while attacks on nuclear power plants and spent fuel storage facilities could create large radiological exclusion zones (National Research Council, 2006). Additionally, nuclear conflicts could easily expand beyond bilateral exchanges. In particular, a US–Russia nuclear exchange would likely involve other NATO states.

High-altitude electromagnetic pulse (HEMP) attacks represent a particularly concerning amplification mechanism. A HEMP is produced when a nuclear weapon is detonated at high altitude (typically above 30 km), generating electromagnetic effects that can damage or disable electric and electronic equipment across vast areas. For example, a detonation at 500 km altitude over the central United States could affect most of North America (Glasstone and Dolan, 1977). Modern industrial facilities depend heavily on HEMP-sensitive electronic systems (Foster et al., 2008), with even seemingly mechanical processes requiring electronic sensors, controllers, and communication networks. The most comprehensive unclassified HEMP risk assessment, the US EMP Commission report (Foster et al., 2008), concluded that long-term catastrophic damage across multiple critical infrastructures is possible but precise predictions remain out of reach due to limited real-world data (Frankel, Scouras and Ullrich, 2015).

5 Discussion and Conclusions

5.1 Global industrial impact

Each scenario's global consequence has two quantifiable parts: a national component (Section 4) and an international spillover through trade. In this section, we estimate the two together by scaling from a documented case of globally transmitted industrial disruption. For the US–Russia exchange, we complement this empirical benchmark with a structural model of world trade linkages that estimates the spillover explicitly.

That benchmark is the 2011 Thailand floods, when severe monsoon flooding inundated a large fraction of the country, including major industrial parks north of Bangkok. A World Bank damage assessment covers five provinces that together held 41% of Thailand's industrial base and 70% of the industrial activity of all flood-affected areas. Their facilities sustained an average of 60% damage (World Bank, 2012). Assuming comparable damage rates in the remaining affected areas (41% × 60% / 70%), approximately 35% of Thailand's industrial capital was incapacitated, or 0.38% of the world's, given Thailand's 1.1% share of world industrial GDP (Central Intelligence Agency, 2024). The shock is estimated to have temporarily reduced world industrial production by 2.5% (The Economist, 2012; Haraguchi and Lall, 2015), an amplification ratio of 6.6 between output forgone and capital lost, both measured as shares of world totals.

For the India–Pakistan scenario, the destroyed capital amounts to approximately 0.10% of the world's industrial base, weighting each country's losses by its share of world industrial output at purchasing-power parity (7% for India and 0.6% for Pakistan; Central Intelligence Agency, 2024). The direct component alone (the national output declines of Section 4.1 weighted by the same shares) reduces world industrial output by approximately 0.5%. Applying the Thailand benchmark amplification ratio implies a global industrial decline of approximately 0.7%.

The US–Russia scenario destroys 26% of industrial capital in each belligerent. Together, the two countries account for 12.5% of world industrial output at purchasing-power parity (Central Intelligence Agency, 2024). Applying our central national output decline of 58% to these shares, world industrial output falls by 7% even if international propagation were zero. Expressed as capital rather than output, the direct loss is 3.2% of the world's industrial base. Extrapolating the Thailand amplification ratio to this much larger shock suggests a global industrial output decline of the order of 20%.

As an independent estimate of international spillover, we asked what decline international trade linkages alone would transmit. The OECD Inter-Country Input–Output tables for 2019 (OECD, 2025) record what each of roughly 4,000 country-sectors sold to every other and to final consumers. In these tables, we fixed the industrial output of the United States and Russia at 42% of baseline and solved for everyone else's output through two complementary channels (Miller and Blair, 2009). The first channel runs backward, through lost customers: industries producing 58% less purchase 58% fewer inputs, and the belligerents' households and firms buy fewer finished goods. We trace these lost sales through every supply chain that ultimately served an American or Russian buyer (a mixed Leontief model). The second runs forward, through lost inputs: American and Russian deliveries of intermediates fall by 58%, and each recipient's output falls by the value of the deliveries it no longer receives. In this treatment, a missing input subtracts only its own value (as though production could otherwise proceed without it), so the resulting total output decline is a floor. The customer channel reduces the rest-of-world industrial output by 4.9% and the input channel by a further 1.4%. Combined with the direct component, global industrial output falls by 13% (11–15% across the 49–70% national interval).

This 13% decline in global industrial output is a floor, not a central estimate. Outside the two belligerents, it accounts only for the proportional disappearance of trade flows, and omits mechanisms that would amplify the shock abroad, such as production halting when one critical input among many is unobtainable, financial contagion and market panic. It nevertheless corroborates the Thailand extrapolation: if this bare accounting already yields 13%, the roughly 20% implied by the Thailand benchmark, which embeds at least some of these compounding effects, is entirely plausible. That benchmark, however, captures few of the mechanisms most relevant here: the 2011 floods struck a single country in an otherwise intact world economy, where the global financial system and shipping networks kept functioning.

The channels that both approaches omit are not marginal. Consider that the 2008–2009 global financial crisis destroyed no physical capital, yet reduced world industrial production by about 13% from peak to trough (CPB Netherlands Bureau for Economic Policy Analysis, 2026). A US–Russia nuclear war could not only destroy more than a quarter of the belligerents' industrial base but also kill tens of millions of people and strain the financial, insurance and shipping arrangements underpinning world trade far more severely than the 2008 crisis did. We conclude that a full-scale US–Russia nuclear war would reduce global industrial output by at least roughly 20%, and plausibly by considerably more.

5.2 Interactions with nuclear winter and food security

This industrial disruption would compound other effects of nuclear war. Modern agriculture's dependence on industrial inputs means that reduced industrial capacity would exacerbate food security challenges posed by nuclear winter. For instance, Ahvo et al. (2023) found that a 25% reduction in agricultural inputs would reduce wheat and maize yields by approximately 15%. These input-driven losses would add to the climate-driven yield declines projected by nuclear winter crop modelling studies (Xia et al., 2022; Blouin et al., 2025), which considered the climate shock alone and assumed that agricultural inputs remain available.

Beyond the loss of agricultural inputs, food security would also be threatened by the disruption of international food trade (Xia et al., 2022; Jehn et al., 2025). This, too, is partly driven by infrastructure loss: trade depends on ports, refineries and fuel supplies, and such facilities are likely nuclear targets. GCIL would also impair humanity's ability to adapt to nuclear winter conditions through measures such as relocating agriculture or scaling up resilient food production (García Martínez, Behr and Denkenberger, 2024; Rivers et al., 2024).

5.3 Implications for deterrence

Given its consequences, GCIL could contribute to nuclear deterrence. The cascading effects through supply chains mean that any nation initiating nuclear conflict risks devastating disruption to its own industrial base, even without suffering direct attacks. This extends beyond simple bilateral trade relationships: through multi-step dependencies in global supply networks, a country might be critically dependent on inputs from trading partners of its nuclear target. This additional deterrent effect is consistent with the historical observation that increased international trade correlates with reduced interstate conflict (Jackson and Nei, 2015), and parallels proposed arguments about the deterrent effects of nuclear winter (Robock et al., 2023).

5.4 Risk mitigation

Beyond preventing nuclear conflict itself, several strategies could help mitigate GCIL risks. Standard supply chain resilience approaches, such as strategic stockpiling of critical industrial inputs and maintaining distributed manufacturing capabilities across regions, provide some protection. While comprehensive EMP hardening would be prohibitively expensive, protecting key facilities through measures like Faraday cage shielding and replacing copper signal cables with fibre optics could help preserve core industrial capabilities. Some US electric utilities have already implemented military-grade EMP protection at their transmission control centres (Electric Power Research Institute, 2019).

5.5 Limitations and future work

Many aspects of post-nuclear war industrial disruption warrant further investigation. We treated industrial infrastructure loss as homogeneous, when different industries would in fact experience varying degrees of disruption. Our framework counts capital while holding labour constant, whereas nuclear war would remove a substantial share of the industrial workforce. However, this is already partially captured in our analysis because the wartime analogue points already embed labour losses. We have not accounted for how surviving industrial facilities might face progressive degradation over time as replacement parts become unavailable, nor explored recovery dynamics.

Future work should examine industrial adaptation potential in post-nuclear scenarios. The COVID-19 pandemic demonstrated capacity for industrial conversion, with cosmetics producers manufacturing hand sanitizer and car manufacturers building ventilators (Elsahn and Siedlok, 2021). Similar strategies have been proposed for global food catastrophes, such as converting paper mills and breweries to produce lignocellulosic sugar for human consumption (Throup et al., 2022). Likewise, biofuel and biomass-based solutions could provide alternative energy sources if the conventional energy infrastructure is disabled (Boyd et al., 2024; Jose et al., 2024; Nelson, Turchin and Denkenberger, 2024).

Integrating GCIL impacts with existing nuclear winter impact models (Rivers et al., 2024) would provide a more comprehensive assessment of post-nuclear war food security challenges. Our analysis of supply chain cascade effects through historical analogues could also help assess other GCIL scenarios, such as extreme pandemics where widespread absenteeism disrupts industrial operations, coordinated cyberattacks on critical infrastructure, or severe space weather events (Schulte In Den Bäumen et al., 2014; Denkenberger et al., 2021; Mulhall et al., 2025).

Acknowledgements

We thank Łukasz G. Gajewski and Jasper Verschuur for useful comments on the manuscript.
Disclosure statement: The authors report there are no competing interests to declare.
Funding: No specific funding was received for this work.
Declaration of generative AI use: Anthropic's Claude large language models (various versions) were used to assist with data analysis and manuscript editing.
Data availability statement: The Python scripts used in this work are available at https://doi.org/10.5281/zenodo.21247253.

References

Abdelkhaliq, M. et al. (2016) "Non Food Needs if Industry is Disabled," in Proceedings of the 6th International Disaster and Risk Conference. 6th International Disaster and Risk Conference, Davos, Switzerland. Available at: https://hal.science/hal-02113489.

Acemoglu, D. et al. (2012) "The Network Origins of Aggregate Fluctuations," Econometrica, 80(5), pp. 1977–2016. Available at: https://doi.org/10.3982/ECTA9623.

Ahvo, A. et al. (2023) "Agricultural input shocks affect crop yields more in the high-yielding areas of the world," Nature Food, 4(12), pp. 1037–1046. Available at: https://doi.org/10.1038/s43016-023-00873-z.

Baqaee, D.R. and Farhi, E. (2019) "The Macroeconomic Impact of Microeconomic Shocks: Beyond Hulten's Theorem," Econometrica, 87(4), pp. 1155–1203. Available at: https://doi.org/10.3982/ECTA15202.

Barrot, J.-N. and Sauvagnat, J. (2016) "Input Specificity and the Propagation of Idiosyncratic Shocks in Production Networks," The Quarterly Journal of Economics, 131(3), pp. 1543–1592. Available at: https://doi.org/10.1093/qje/qjw018.

Batcher, R.T. (2004) "The Consequences of an Indo-Pakistani Nuclear War," International Studies Review, 6(4), pp. 135–162. Available at: https://doi.org/10.1111/j.1521-9488.2004.00453.x.

Baum, S.D. (2015) "Confronting the threat of nuclear winter," Futures, 72, pp. 69–79. Available at: https://doi.org/10.1016/j.futures.2015.03.004.

Blouin, S. et al. (2024) "Assessing the Impact of Catastrophic Electricity Loss on the Food Supply Chain," International Journal of Disaster Risk Science, 15(4), pp. 481–493. Available at: https://doi.org/10.1007/s13753-024-00574-6.

Blouin, S. et al. (2025) "Strategic crop relocation could substantially mitigate nuclear winter yield losses." EarthArXiv. Available at: https://doi.org/10.31223/X5GN09.

Boyd, M. et al. (2024) "Mitigating imported fuel dependency in agricultural production: Case study of an island nation's vulnerability to global catastrophic risks," Risk Analysis, 44(10), pp. 2360–2376. Available at: https://doi.org/10.1111/risa.14297.

Brode, H.L. and Small, R.D. (1984) Fire Damage and Strategic Targeting. Pacific-Sierra Research Corporation. Available at: https://apps.dtic.mil/sti/pdfs/ADA159280.pdf.

Cabinet Office (2012) Annual Report on National Accounts for FY2011: Gross Domestic Product by Kind of Economic Activity (nominal). Economic and Social Research Institute, Government of Japan. Available at: https://www.esri.cao.go.jp/jp/sna/data/data_list/kakuhou/files/h23/tables/23fcm3nf_jp.xls.

Carvalho, V.M. et al. (2021) "Supply Chain Disruptions: Evidence from the Great East Japan Earthquake," The Quarterly Journal of Economics, 136(2), pp. 1255–1321. Available at: https://doi.org/10.1093/qje/qjaa044.

Central Intelligence Agency (2024) GDP - composition, by sector of origin, The World Factbook. Available at: https://www.cia.gov/the-world-factbook/field/gdp-composition-by-sector-of-origin/ (Accessed: October 30, 2024).

Clary, C. and Narang, V. (2019) "India's Counterforce Temptations: Strategic Dilemmas, Doctrine, and Capabilities," International Security, 43(3), pp. 7–52. Available at: https://doi.org/10.1162/isec_a_00340.

Coupe, J. et al. (2019) "Nuclear Winter Responses to Nuclear War Between the United States and Russia in the Whole Atmosphere Community Climate Model Version 4 and the Goddard Institute for Space Studies ModelE," Journal of Geophysical Research: Atmospheres, 124(15), pp. 8522–8543. Available at: https://doi.org/10.1029/2019JD030509.

CPB Netherlands Bureau for Economic Policy Analysis (2026) World Trade Monitor, November 2025 release: world industrial production series. The Hague: CPB. Available at: https://www.cpb.nl/en/world-trade-monitor/cpb-world-trade-monitor-november-2025 (Accessed: July 6, 2026).

Curley, L. (2011) Japan: Some Economic Consequences of the Kobe Earthquake of 1995, Haver Analytics. Available at: https://www.haver.com/articles/archive-economy-japan-some-economic-consequences-of-the-kobe-earthquake-of-1995 (Accessed: July 6, 2026).

Daugherty, W., Levi, B. and Von Hippel, F. (1986) "Casualties Due to the Blast, Heat, and Radioactive Fallout from Various Hypothetical Nuclear Attacks on the United States," in The Medical Implications of Nuclear War. Washington, DC: National Academy Press, pp. 207–232.

Denkenberger, D. et al. (2017) "Feeding everyone if the sun is obscured and industry is disabled," International Journal of Disaster Risk Reduction, 21, pp. 284–290. Available at: https://doi.org/10.1016/j.ijdrr.2016.12.018.

Denkenberger, D. et al. (2021) "Long-term cost-effectiveness of interventions for loss of electricity/industry compared to artificial general intelligence safety," European Journal of Futures Research, 9(1), p. 11. Available at: https://doi.org/10.1186/s40309-021-00178-z.

Djankov, S. and Blinov, O. (2022) Assessment of damages to Ukraine's productive capacity, Centre for Economic Policy Research. Available at: https://cepr.org/voxeu/columns/assessment-damages-ukraines-productive-capacity (Accessed: October 27, 2024).

Electric Power Research Institute (2019) High-Altitude Electromagnetic Pulse and the Bulk Power System: Potential Impacts and Mitigation Strategies. 000000003002014979. Available at: https://www.epri.com/research/products/3002014979.

Elsahn, Z. and Siedlok, F. (2021) "'Can we build it? Yes, we can!' complexities of resource re-deployment to fight pandemic.," Industrial Marketing Management, 93, pp. 191–207. Available at: https://doi.org/10.1016/j.indmarman.2021.01.013.

European Central Bank (2011) Monthly Bulletin - May 2011. Frankfurt am Main: European Central Bank. Available at: https://www.ecb.europa.eu/pub/pdf/mobu/mb201105en.pdf.

Federal Reserve (2005) "Industrial Production and Capacity Utilization." Available at: https://www.federalreserve.gov/releases/g17/20051014/g17.pdf.

Federal Reserve Bank of St. Louis (2004) U.S. Regional Data, FRED. Available at: https://fred.stlouisfed.org/categories/3008 (Accessed: October 31, 2024).

FEMA (2006) Summary Report on Building Performance: Hurricane Katrina 2005. FEMA. Available at: https://www.fema.gov/sites/default/files/2020-08/fema_548_summary_report_building_performance_hurricane_katrina_2005.pdf.

Fire and Disaster Management Agency (2022) Report on the 2011 off the Pacific coast of Tohoku Earthquake (Great East Japan Earthquake), No. 162 [平成23年(2011年)東北地方太平洋沖地震（東日本大震災）について（第162報）]. Tokyo: FDMA. Available at: https://www.fdma.go.jp/disaster/higashinihon/items/162.pdf.

Foster, J.S.Jr. et al. (2008) Report of the Commission to Assess the Threat to the United States from Electromagnetic Pulse (EMP) Attack: Critical National Infrastructures. Available at: https://apps.dtic.mil/sti/citations/ADA484672 (Accessed: November 26, 2020).

Frankel, M., Scouras, J. and Ullrich, G. (2015) The Uncertain Consequences of Nuclear Weapons Use. Johns Hopkins University Applied Physics Laboratory. Available at: https://www.jhuapl.edu/sites/default/files/2022-12/UncertainConsequencesofNuclearWeapons.pdf.

García Martínez, J.B., Behr, J. and Denkenberger, D. (2024) "Food without agriculture: Food from CO2, biomass and hydrocarbons to secure humanity's food supply against global catastrophe," Trends in Food Science & Technology, 150. Available at: https://doi.org/10.1016/j.tifs.2024.104609.

Glasstone, S. and Dolan, P.J. (1977) The Effects of Nuclear Weapons. United States Department of Defense and United States Department of Energy.

Haklay, M. and Weber, P. (2008) "OpenStreetMap: User-Generated Street Maps," IEEE Pervasive Computing, 7(4), pp. 12–18. Available at: https://doi.org/10.1109/MPRV.2008.80.

Hallegatte, S. (2014) "Modeling the Role of Inventories and Heterogeneity in the Assessment of the Economic Costs of Natural Disasters," Risk Analysis, 34(1), pp. 152–167. Available at: https://doi.org/10.1111/risa.12090.

Haraguchi, M. and Lall, U. (2015) "Flood risks and impacts: A case study of Thailand's floods in 2011 and research questions for supply chain decision making," International Journal of Disaster Risk Reduction, 14, pp. 256–272. Available at: https://doi.org/10.1016/j.ijdrr.2014.09.005.

Hyōgo Prefecture (2006) Status of Recovery and Reconstruction from the Great Hanshin-Awaji Earthquake [阪神・淡路大震災の復旧・復興の状況について]. Kobe: Hyōgo Prefectural Government. Available at: https://web.pref.hyogo.lg.jp/kk41/documents/fukkyuufukkou202601ver2.pdf.

Inoue, H. and Todo, Y. (2019) "Firm-level propagation of shocks through supply-chain networks," Nature Sustainability, 2(9), pp. 841–847. Available at: https://doi.org/10.1038/s41893-019-0351-x.

Inoue, H. and Todo, Y. (2022) "Propagation of Overseas Economic Shocks through Global Supply Chains: Firm-level Evidence," SSRN [Preprint]. Available at: https://doi.org/10.2139/ssrn.4183736.

Institute of Energy Economics Japan (2011) "Japan Energy Brief No. 12 (March 2011)." Tokyo: IEEJ. Available at: https://eneken.ieej.or.jp/en/jeb/1103.pdf.

Jackson, M.O. and Nei, S. (2015) "Networks of military alliances, wars, and international trade," Proceedings of the National Academy of Sciences, 112(50), pp. 15277–15284. Available at: https://doi.org/10.1073/pnas.1520970112.

Jehn, F.U. et al. (2025) "Food trade disruption after global catastrophes," Earth System Dynamics, 16(5), pp. 1585–1603. Available at: https://doi.org/10.5194/esd-16-1585-2025.

Jordahl, K. et al. (2020) "geopandas/geopandas: v0.8.1." Zenodo. Available at: https://doi.org/10.5281/ZENODO.3946761.

Jose, L. et al. (2024) "Be clever or be cold: repurposed ovens for space heating following global catastrophic infrastructure loss." EarthArXiv. Available at: https://doi.org/10.31223/X5P693.

Kang, H., Lee, K.-M. and Yang, J.-S. (2024) "The potential for cascading failures in the international trade network," PLOS ONE. Edited by M. Jakovljevic, 19(3), p. e0299833. Available at: https://doi.org/10.1371/journal.pone.0299833.

Katz, A.M. (1982) Life after Nuclear War: The Economic and Social Impacts of Nuclear Attacks on the United States. Cambridge, Mass.: Ballinger Pub Co.

Kōsai, Y. and Goble, A. (1989) "The postwar Japanese economy, 1945–1973," in P. Duus (ed.) The Cambridge History of Japan. 1st ed. Cambridge University Press, pp. 494–538. Available at: https://doi.org/10.1017/CHOL9780521223577.011.

Kristensen, H.M. et al. (2024a) "Indian nuclear weapons, 2024," Bulletin of the Atomic Scientists, 80(5), pp. 326–342. Available at: https://doi.org/10.1080/00963402.2024.2388470.

Kristensen, H.M. et al. (2024b) "Russian nuclear weapons, 2024," Bulletin of the Atomic Scientists, 80(2), pp. 118–145. Available at: https://doi.org/10.1080/00963402.2024.2314437.

Kristensen, H.M., Korda, M. and Johns, E. (2023) "Pakistan nuclear weapons, 2023," Bulletin of the Atomic Scientists, 79(5), pp. 329–345. Available at: https://doi.org/10.1080/00963402.2023.2245260.

Kurita, M. (2018) "China-India Relationship and Nuclear Deterrence," NIDS Journal of Defense and Security, 19, pp. 37–61.

Linz, S.J. (1984) World War II and Soviet Economic Growth, 1940-1953. BEBR Faculty Working Paper No. 1038. Urbana-Champaign: University of Illinois. Available at: https://www.ideals.illinois.edu/items/29011.

Malik, J. (1985) The Yields of the Hiroshima and Nagasaki Nuclear Explosions. LA-8819. Los Alamos, NM: Los Alamos National Laboratory. Available at: https://www.osti.gov/biblio/1489669.

Meier, M. and Pinto, E. (2024) "COVID-19 Supply Chain Disruptions," European Economic Review, 162, p. 104674. Available at: https://doi.org/10.1016/j.euroecorev.2024.104674.

Miller, R.E. and Blair, P.D. (2009) Input-Output Analysis: Foundations and Extensions. 2nd edn. Cambridge: Cambridge University Press.

Moersdorf, J. et al. (2024) "The Fragile State of Industrial Agriculture: Estimating Crop Yield Reductions in a Global Catastrophic Infrastructure Loss Scenario," Global Challenges, 8(1), p. 2300206. Available at: https://doi.org/10.1002/gch2.202300206.

Mulhall, J. et al. (2025) "Developing back-up plans to protect vital sectors in extreme pandemics." Available at: https://doi.org/10.31219/osf.io/h7wte_v2.

Nakayama, I. (1963) Industrialization of Japan. Tokyo: Centre for East Asian Cultural Studies.

NASEM (2025) Potential Environmental Effects of Nuclear War. Washington, D.C.: National Academies Press. Available at: https://doi.org/10.17226/27515.

National Research Council (2006) Safety and Security of Commercial Spent Nuclear Fuel Storage: Public Report. Washington, D.C.: National Academies Press, p. 11263. Available at: https://doi.org/10.17226/11263.

Nelson, D., Turchin, A. and Denkenberger, D. (2024) "Wood Gasification: A Promising Strategy to Extend Fuel Reserves after Global Catastrophic Electricity Loss," Biomass, 4(2), pp. 610–624. Available at: https://doi.org/10.3390/biomass4020033.

OECD (2025) OECD Inter-Country Input-Output (ICIO) Tables, 2025 edition. Paris: Organisation for Economic Co-operation and Development. Available at: https://oe.cd/icio (Accessed: July 3, 2026).

Office of Technology Assessment (1979) The Effects of Nuclear War. Washington, D.C. Available at: https://ota.fas.org/reports/7906.pdf.

OpenStreetMap contributors (2024) "OpenStreetMap." Available at: www.openstreetmap.org.

Overy, R.J. (2001) "World War II: The Bombing of Germany," in A. Stephens (ed.) The war in the air 1914-1994. Maxwell Air Force Base, Alabama: Air University Press, pp. 107–141.

Philippe, S. (2023) Who Would Take the Brunt of an Attack on U.S. Nuclear Missile Silos?, Scientific American. Available at: https://www.scientificamerican.com/article/who-would-take-the-brunt-of-an-attack-on-u-s-nuclear-missile-silos/ (Accessed: October 27, 2024).

Philippe, S. and Stepanov, I. (2023) "Radioactive Fallout and Potential Fatalities from Nuclear Attacks on China's New Missile Silo Fields," Science & Global Security, 31(1–2), pp. 3–15. Available at: https://doi.org/10.1080/08929882.2023.2215590.

Plumpe, W. (2016) "Germany as an Industrial Country 1945–2008," in Plumpe, W., German Economic and Business History in the 19th and 20th Centuries. London: Palgrave Macmillan UK, pp. 239–280. Available at: https://doi.org/10.1057/978-1-137-51860-6_10.

Reisner, J. et al. (2018) "Climate Impact of a Regional Nuclear Weapons Exchange: An Improved Assessment Based on Detailed Source Calculations," Journal of Geophysical Research: Atmospheres, 123(5), pp. 2752–2772. Available at: https://doi.org/10.1002/2017JD027331.

Reisner, J. et al. (2019) "Reply to Comment by Robock et al. (2019) on 'Climate impact of a regional nuclear weapons exchange: An improved assessment based on detailed source calculations'," Journal of Geophysical Research: Atmospheres, 124, pp. 12959–12962. Available at: https://doi.org/10.1029/2019JD031281.

Richard, T.T. (2017) "Nuclear Weapons Targeting: Evolution of Law and U.S. Policy," Military Law Review, 224(4), pp. 872–978. Available at: https://doi.org/10.2139/ssrn.2924907.

Rivers, M. et al. (2024) "Food System Adaptation and Maintaining Trade Could Mitigate Global Famine in Abrupt Sunlight Reduction Scenarios," Global Food Security, 43(100807). Available at: https://doi.org/10.1016/j.gfs.2024.100807.

Robock, A., Toon, O.B. and Bardeen, C.G. (2019) "Comment on 'Climate impact of a regional nuclear weapon exchange: An improved assessment based on detailed source calculations' by Reisner et al.," Journal of Geophysical Research: Atmospheres, 124, pp. 12953–12958. Available at: https://doi.org/10.1029/2019JD030777.

Robock, A. et al. (2023) "Opinion: How fear of nuclear winter has helped save the world, so far," Atmospheric Chemistry and Physics, 23(12), pp. 6691–6701. Available at: https://doi.org/10.5194/acp-23-6691-2023.

Schulte In Den Bäumen, H. et al. (2014) "How severe space weather can disrupt global supply chains," Natural Hazards and Earth System Sciences, 14(10), pp. 2749–2759. Available at: https://doi.org/10.5194/nhess-14-2749-2014.

Scouras, J. (2019) "Nuclear War as a Global Catastrophic Risk," Journal of Benefit-Cost Analysis, 10(2), pp. 274–295. Available at: https://doi.org/10.1017/bca.2019.16.

Silva, F.B. e et al. (2014) "Estimating Demand for Industrial and Commercial Land Use Given Economic Forecasts," PLOS ONE, 9(3), p. e91991. Available at: https://doi.org/10.1371/journal.pone.0091991.

Sims, K. et al. (2022) "LandScan Global 2022." Oak Ridge National Laboratory. Available at: https://doi.org/10.48690/1529167.

Statistics Bureau of Japan (2012) Historical Statistics of Japan. Tables 8-8 (Manufactured goods shipments by prefecture, Census of Manufactures) and 21-1 (Dwellings by prefecture, Housing and Land Surveys 1948-2008). Tokyo: Statistics Bureau, Ministry of Internal Affairs and Communications. Archived at: https://web.archive.org/web/20130122145622/http://www.stat.go.jp/data/chouki/zuhyou/08-08.xls and https://web.archive.org/web/20130122145619/http://www.stat.go.jp/data/chouki/zuhyou/21-01.xls.

Tasleem, S. (2016) Pakistan's Nuclear Use Doctrine, Carnegie Endowment for International Peace. Available at: https://carnegieendowment.org/research/2016/06/pakistans-nuclear-use-doctrine (Accessed: October 23, 2024).

Teter, D. (2022) "OPEN-RISOP." GitHub. Available at: https://github.com/davidteter/OPEN-RISOP.

The Committee for the Compilation of Materials on Damage Caused by the Atomic Bomb (1981) Hiroshima and Nagasaki : the physical, medical, and social effects of the atomic bombings. New York: Basic Books.

The Economist (2012) "Counting the cost of calamities," The Economist. Available at: https://www.economist.com/briefing/2012/01/14/counting-the-cost-of-calamities (Accessed: October 27, 2024).

The Manhattan Engineer District (1946) The Atomic Bombings of Hiroshima and Nagasaki. United States Army. Available at: https://www.atomicarchive.com/resources/documents/med/index.html.

Throup, J. et al. (2022) "Rapid repurposing of pulp and paper mills, biorefineries, and breweries for lignocellulosic sugar production in global food catastrophes," Food and Bioproducts Processing, 131, pp. 22–39. Available at: https://doi.org/10.1016/j.fbp.2021.10.012.

Toon, O.B. et al. (2007) "Atmospheric effects and societal consequences of regional scale nuclear conflicts and acts of individual nuclear terrorism," Atmospheric Chemistry and Physics, 7(8), pp. 1973–2002.

Toon, O.B. et al. (2019) "Rapidly expanding nuclear arsenals in Pakistan and India portend regional and global catastrophe," Science Advances, 5(10), p. eaay5478. Available at: https://doi.org/10.1126/sciadv.aay5478.

Toon, O.B., Robock, A. and Turco, R.P. (2008) "Environmental consequences of nuclear war," Physics Today, 61(12), pp. 37–42. Available at: https://doi.org/10.1063/1.3047679.

United Nations Economic Commission for Europe (2024) UNECE Statistical Database. Available at: https://w3.unece.org/PXWeb2015/pxweb/en/STAT/ (Accessed: October 27, 2024).

US Energy Information Administration (2012) Country Analysis Brief: Japan (last updated June 4, 2012). Washington, D.C.: EIA. Archived at: https://web.archive.org/web/20130604063403/http://www.eia.gov/countries/cab.cfm?fips=JA.

Voznesensky, N. (1948) The Economy of the USSR During World War II. Washington, D.C.: Public Affairs Press.

Wagman, B.M. et al. (2020) "Examining the Climate Effects of a Regional Nuclear Weapons Exchange Using a Multiscale Atmospheric Modeling Approach," Journal of Geophysical Research: Atmospheres, 125(24), p. e2020JD033056. Available at: https://doi.org/10.1029/2020JD033056.

Winter, S.G., Jr. (1963) Economic Viability After Thermonuclear War: The Limits of Feasible Production. RM-3436-PR. Santa Monica, CA: RAND Corporation.

World Bank (2012) Thai Flood 2011: Rapid Assessment for Resilient Recovery and Reconstruction Planning. Bangkok: World Bank. Available at: https://hdl.handle.net/10986/26862 (Accessed: October 27, 2024).

Xia, L. et al. (2022) "Global food insecurity and famine from reduced crop, marine fishery and livestock production due to climate disruption from nuclear war soot injection," Nature Food, 3(8), pp. 586–596. Available at: https://doi.org/10.1038/s43016-022-00573-0.