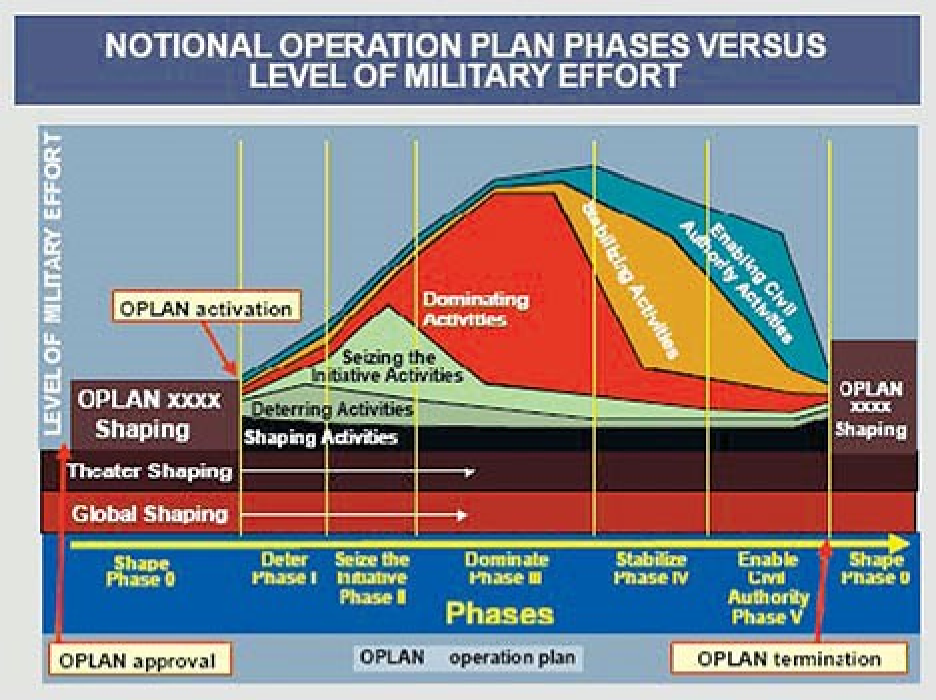
# Rapid Relief and Reconstruction in a DPRK Humanitarian Energy Crisis

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## I. SUMMARY

This scoping paper identifies key issues associated with rapid relief and reconstruction for the provision of energy services that could arise in the Democratic People's Republic of Korea (DPRK). This situation could occur in three ways: a) partial energy system failure with ensuing complex humanitarian emergency; b) collapse of the DPRK state with an even greater complex humanitarian emergency due in part to failure to deliver essential energy services; and c) war resulting in

uncontested occupation of the DPRK by US-ROK and UNC forces. The authors emphasize that these latter two scenarios are not probable in the near- or even longer-term. The first scenario, however, is certainly possible at any time due to the parlous state of the DPRK energy system, especially in the winter. Indeed, the already-complex context of the DPRK nuclear weapons issue is rendered even more uncertain by the possibility that the DPRK may experience pervasive, energy system-wide shocks—the complete failure of the electricity grid, for example—that would demand a massive humanitarian energy relief operation at a time of high tension but not actual war. The strategies developed to rapidly deliver energy relief and to commence energy reconstruction also need to be robust in a range of security circumstances, so that politically plausible and physically realistic policy options exist for decision-makers if and when they are confronted by such an imperative.

Because the social and humanitarian results of all three scenarios are severe and very large-scale, it is crucial that the international community have a clear plan to provide energy services in such an event. Moreover, many elements of a plan to deal with a humanitarian energy crisis in the DPRK are similar to those that the international community should implement in engagement with the DPRK in the near-term future to settle the nuclear issue. Thus, this analysis serves multiple purposes, some of them possibly immediate, some of them more relevant to policy makers in the medium or long-term, hopefully, some of them never.

The relief phase in either of the two state-failure cases could commence either in mid-winter or in mid-summer as two extreme defining circumstances that would shape the ensuing energy crisis in the first phase of immediate emergency relief (running for one year). The reconstruction phase would commence in one year, at which time (depending on the scenario) reconstruction would become increasingly integrated into inter-Korean (and therefore, ROK) Peninsular-wide energy development planning and national economic decision-making.

The possible circumstances that could bring about a DPRK energy crisis beyond the chronic shortages and constant failures that have become normal in the DPRK over the last two decades are varied, but they combine to form a fundamental matrix of possible outcomes for which the international community needs to anticipate meeting large-scale desperate needs for large populations (greater than say 100,000 people in one location), as well as addressing emerging economic development priorities and overwhelming political imperatives to attend to provision of energy services in the DPRK. The types and scale of needs for energy services will guide strategic options in the relief phase.

Reconstruction strategies that will serve as the basis for delivering energy services to the most vulnerable populations, to at-risk economic sectors, and to energy-deficit regions in a variety of state-failure circumstances will also be maximally resilient to the impacts of major unanticipated but inevitable energy shocks consistent with state failure.  In this paper, we provide a selection of reconstruction strategies applicable under multiple circumstances, and also guided by development goals and economic principles.

## II. Special Report by Peter Hayes, David von Hippel and Roger Cavazos

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# 1 BACKGROUND

In the last decade, the United States and its allies and partners have confronted the energy challenges of post-conflict relief and reconstruction in two conflict zones, Iraq and Afghanistan. In both cases, these challenges were not anticipated fully, and the resulting political, security, economic, and humanitarian costs of not fully meeting relief and reconstruction needs, including energy needs, were high. Experience in these conflict zones offers significant lessons for the development of future post-conflict approaches.

The DPRK presents a particularly challenging case for the international community with regard to post-collapse or post-conflict relief and reconstruction. In Korea, the primary potential respondents to the three types of large-scale energy-driven humanitarian crisis referred to in the introduction are the ROK, the United States (in particular, the US Department of Defense (US-DOD), China, and Russia. In this paper, we will focus on potential US-DOD and ROK responses. Separate analysis is needed for potential Chinese, Russian, and international non-governmental and inter-governmental agency energy humanitarian responses, each of which have their own established approaches and methods.[1]

The US-DOD itself has a standard “frame” by which it considers how best to provide humanitarian assistance, including humanitarian and then reconstruction energy assistance.[2] Considering the six “phases” of conflict management (phases 0 through 5) that structure the US-DOD’s conflict preparation[3], although energy issues have figured prominently in what might be considered the analog to Phase 1 of the DOD Operational Plan Phases (as shown in Figure 1), namely influencing perceptions and shaping behaviors of the DPRK, especially via international cooperation, less attention has been given to the issues that would face the United States, the Republic of Korea (ROK), and their international partners in the case of large-scale DPRK energy system failure, or in case of either of the two less likely scenarios of regime collapse and ensuing chaos, or post-conflict (that is, post a second full scale Korean War) phase 4 relief and phase 5 reconstruction of the energy economy in what is now the DPRK.

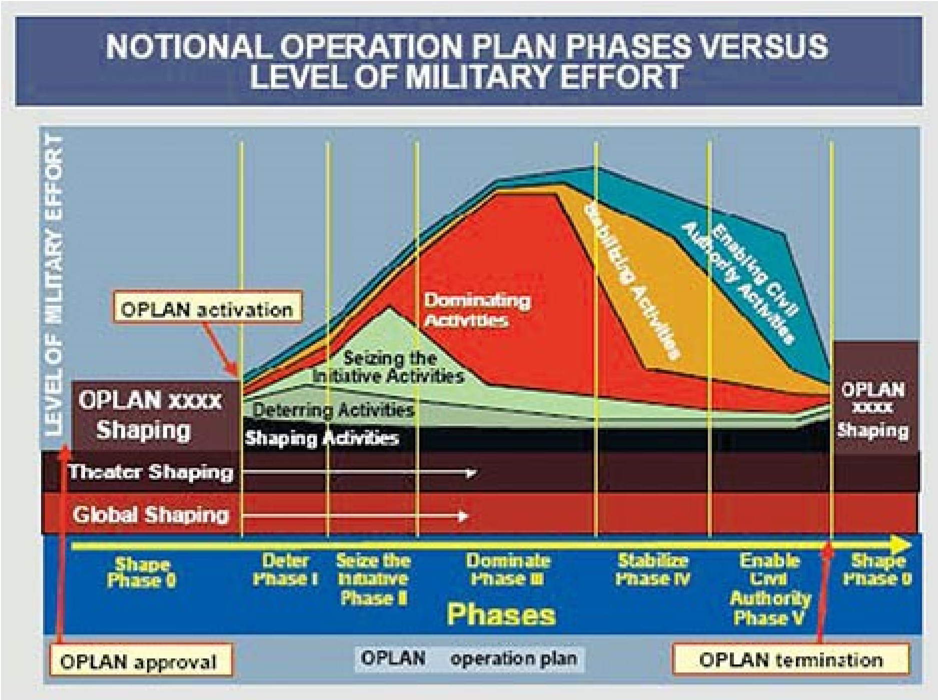


**Figure 1: Joint Operational Planning Phases**

Source: US Department of Defense. *Joint Publication 3-0: Joint Operations.* Washington, DC: 2006, p IV-26.

In part, this paucity of analysis and of anticipatory contingency planning regarding a potential partial or catastrophic (that is, wartime) DPRK humanitarian energy crisis is the result of the extraordinary opacity of the DPRK with regard to socio-economic and other data that are supplied by most states to the international community or in the course of their normal transactions with the external world. Considerable physical data, however, have been collected, have been tested via a variety of techniques, and, in some instances, have confirmed by measurement or observation inside the DPRK. These physical data have been used by Nautilus Institute to create a standard energy supply-demand model for the DPRK. Although the underlying data are uneven in quality, this model is remarkably rich in detail, and provides a unique basis for analysis of possible energy pathways in the DPRK over a variety of future conditions. At times, the database has been deepened in cooperation with North and South Korean experts; and has also benefited from the data and insights gleaned from many international experts who have worked inside the DPRK in different parts of the DPRK energy sector (including Nautilus staff). The latter information was solicited systematically via the Nautilus-organized DPRK Expert Energy Working Group that met three times in between 2006-2010, including once in the US (2006), and twice in Beijing (2008 and 2010), supported in part by the U.S. Department of Energy.[4]

The data available are sufficient to qualitatively and semi-quantitatively identify highly vulnerable populations, "brittle" (vulnerable to physical, social, or economic stresses) aspects of the supply-demand structure of the DPRK energy economy, energy deficit regions and locations, and unanticipated shocks that could erupt concurrently with the possible relief and reconstruction pathways. The basic data (energy supply-demand balance and supporting analysis) needs to be updated and in some sectors and sub-sectors refined to support the analysis outlined below.

Due to the inherent uncertainty that characterizes complex, protracted emergencies such as a large-scale energy system failure in the DPRK or in post-conflict circumstances, developing precise plans, linear strategies, and targeted outcomes will not address the needs for rapid relief and reconstruction in the DPRK. Rather, strategies and related deep understanding need to be developed between planners, logisticians, unified commands, allies, partners, and international agencies as to the kind of shocks and needs that will arise, and the types of responses and capacities that will be needed. These should be defined and scaled with guidance from qualitative and quantitative analysis grounded in DPRK-specific data and deep knowledge of its social, institutional and technological characteristics. To the extent possible, these ideas should be presented to and discussed with not only other international key players such as China and Japan in the context of a regional response to a potential humanitarian energy crisis, but also with DPRK energy planners to review priorities and possible avenues of cooperative action.

The most salient features of the relief strategies will be situational awareness and rapid learning, agility and rapid adaptation, diversity of approach and players, and enlisting and leveraging pre-existing local capacity to respond to needs and improvise solutions.[5] The context in the DPRK is further complicated by the fact that the ROK government (ROKG), of necessity and by right the United States' ally and partner in relief and reconstruction of North Korea, likely will have a lead external role in setting priorities, making tradeoffs, and directing relief and reconstruction efforts in response to a desperate energy situation arising in the DPRK. This political reality makes it all the more important to explore these issues early and often with ROK counterparts and energy planners in the DPRK Energy Task Force of the ROKG so that the U.S. and other allies can shape this strategy and prefigure roles in relation to those which the ROKG will insist lies within its purview.

## 2 ENERGY SUPPLY-DEMAND STRUCTURE

The most current energy supply-demand balance for the DPRK published by Nautilus is shown below.[6] This balance exhibits a number of peculiar DPRK structural features, in comparison with "normal" countries with a similar low level of per capita income. First, coal is predominant, and industrial energy use is the major user of coal, even to a greater extent than in China. Coal is critical for not only industrial process heat, but also for public building and household heating and cooking, either directly, via small furnace-boilers or household stoves, or via power station district heat distribution systems where combined heat and power or heat-only district heating systems are located near or in the middle of cities. Coal mines are unsafe, many are still inundated from floods in the 1990s and since, and deliveries of coal from mine to end user are unreliable much of the time. DPRK coal is also reportedly often of poor quality and low energy content. Many small settlements and collective farms rely on their own small coal mines, which introduces an element of local resilience in these areas—provided the means to transport the local coal to local users is available and fueled.

Second, biomass is a very important fuel, especially in rural areas. This includes wood fuel and, to a much lesser extent, charcoal, as well as agricultural wastes. Significant externalities exist for wood fuel and crop wastes use, including deforestation, loss of habitat and opportunity to forage for food or to hunt for wildlife; erosion; local and indoor air pollution; diversion of nutrients from mulch and compost used in food production to fuel, and other consequences. In the short-term, the forced reversion to and expanded reliance on biomass since 1991 lends an element of local resilience to rural population energy supply.

Third, refined products are very scarce and expensive. Unsurprisingly, the Korean People's Army (KPA) is the dominant user of refined products. Consequently, public transport and harvesting and food processing activities are often halted or slowed due to fuel shortages, especially of diesel, although army trucks in the DPRK often simultaneously serve to move military and civilian goods, soldiers, and civilians.

Fourth, electricity supply is constrained by seasonal availability of fuel (especially stored or run-o--river hydropower which runs low in the winter period), obsolete and worn-out generation and transmission and distribution equipment, and the failure of end use equipment, especially electric motors, due to huge fluctuations in voltage and frequency on the DPRK grid. As with coal and biomass, the fragmentation of the unified national grid (already with relatively low interconnection) into multiple grids, effectively operating on different frequencies, paradoxically imbues a degree of resilience to the power system that is now really a collection of de facto regional and mini-grids, combined with extensive use of backup diesel and gasoline generators (mostly imported from China) in major cities, businesses, and even households.  Recent years, in fact, have seen a burgeoning trade in small solar photovoltaic power generation systems, in capacities of tens to hundreds of watts, imported from China, and purchased by households and small businesses.[7] In this case, resilience stems from the recent trends toward reliance on local resources rather than central supplies, meaning that if central supplies are lost, local power may still be available. (Note: this resilience is achieved at a high cost of foregoing the system-level advantages of operating a unified national grid including increased generation reserve margins (and thus higher required generation capacity), reduced density of interconnection and reliability, and other factors, but the costs of coping with an unreliable central grid have already been incurred in the DPRK, and the population and industry have to a large extent adjusted already). Large hydropower dams are a mainstay of the system, but many of these plants are antiques—some from the Japanese colonial era—and will need refurbishment as well as stringent safety reviews to ensure that downstream populations are not at risk from dam failure.

Fifth, the DPRK is highly dependent on China for supplies of crude oil and refined products, the former delivered mostly via one pipeline to the DPRK's refinery in the Northwest. The reported reactivation of the Rajin-Songbong oil refinery (the DPRK's other major refinery, located in the Northeast) in a Mongolian-Russian-North Korean deal, may reduce the DPRK's dependence on Chinese crude oil supplies, although it remains unclear where the outputs of the refinery would go. Unlike Iraq, the DPRK is not a significant supplier of fuel except for the increasing quantities of coal exported to China. By any measure, its energy economy is highly insecure.

Finally, the energy economy is also bifurcated in many dimensions into military and non-military supply, transformation, and end-use sectors. Although we estimate that the military in non-wartime operations are a relatively small fraction (about 8 percent) of total secondary energy use, the military has its own electricity distribution grid in many places, has substantial stockpiles of oil products and perhaps other fuels, runs many of the factories that appear in other sectors, and most importantly, has first call in a crisis on fuel and fuel cycle facilities in the DPRK.

**Estimated DPRK Energy Balance for the Year 2010**

| UNITS: TERAJOULES (TJ) | COAL & COKE | CRUDE OIL | REFINED PROD. | HYDRO/ NUCLEAR | WOOD/ BIOMASS | CHARCOAL | HEAT | ELECTRICITY | TOTAL |
|---|---|---|---|---|---|---|---|---|---|
| ENERGY SUPPLY | 341,973 | 25,309 | 12,744 | 42,864 | 213,315 | - | - | 1,408 | 637,613 |
| Domestic Production | 450,128 | 251 | | 42,864 | 201,315 | | | | 694,558 |
| Imports | 12,336 | 25,058 | 14,414 | | 12,000 | | | 1,954 | 65,762 |
| Exports | 120,491 | | 1,670 | | | | | 546 | 122,707 |
| Inputs to International Marine Bunkers | | | | | | | | | - |
| Stock Changes | | | - | | | | | | - |
| ENERGY TRANSFORMATION | (81,433) | (25,309) | 17,349 | (42,864) | (6,063) | 1,819 | 3,726 | 35,483 | (97,292) |
| Electricity Generation | (52,637) | | (6,445) | (42,864) | | | 3,617 | 55,286 | (43,043) |
| Petroleum Refining | | (25,309) | 25,309 | | | | | (149) | (149) |
| Coal Production/Preparation | (21,548) | | | | | | | (2,918) | (24,466) |
| Charcoal Production | | | | | (6,063) | 1,819 | | | (4,244) |
| Coke Production | | | | | | | | | - |
| District Heat Production | (1,738) | | (35) | | | | 1,100 | | (673) |
| Other Transformation | | | | | | | | | - |
| Own Use | | | (1,480) | | | | | (2,199) | (3,679) |
| Losses | (5,511) | | | | | | (990) | (14,537) | (21,038) |
| FUELS FOR FINAL CONSUMPTION | 260,540 | - | 30,093 | - | 207,251 | 1,819 | 3,726 | 36,891 | 540,321 |
| ENERGY DEMAND | 260,548 | - | 30,357 | - | 207,253 | 1,820 | 3,726 | 36,892 | 540,595 |
| *INDUSTRIAL SECTOR* | 140,031 | - | 5,717 | - | 836 | - | - | 14,206 | 160,789 |
| Iron and Steel | 53,561 | | | | | | | 2,869 | 56,430 |
| Cement | 22,860 | | 2,388 | | | | | 1,461 | 26,710 |
| Fertilizers | 1,950 | | 338 | | | | | 1,535 | 3,823 |
| Other Chemicals | 1,848 | | | | | | | 1,092 | 2,940 |
| Pulp and Paper | 642 | | | | 642 | | | 149 | 1,433 |
| Other Metals | 15,133 | | | | | | | 2,633 | 17,766 |
| Other Minerals | 4,600 | | 2,477 | | | | | 222 | 7,299 |
| Textiles | 5,269 | | - | | | | | 448 | 5,716 |
| Building Materials | 19,090 | | - | | | | | 58 | 19,148 |
| Non-specified Industry | 15,077 | | 514 | | 194 | | | 3,739 | 19,523 |
| *TRANSPORT SECTOR* | - | - | 9,894 | - | 654 | - | - | 4,185 | 14,734 |
| Road | | | 8,250 | | 654 | | | | 8,904 |
| Rail | - | | 464 | | | | | 4,185 | 4,649 |
| Water | - | | 338 | | | | | | 338 |
| Air | | | 842 | | | | | | 842 |
| Non-Specified | | | - | | | | | - | - |
| *RESIDENTIAL SECTOR* | 76,961 | - | 2,038 | - | 158,142 | 1,820 | 2,419 | 4,050 | 245,430 |
| Urban | 63,471 | | 1,869 | | 35,268 | 1,126 | 2,419 | 3,550 | 107,703 |
| Rural | 13,490 | | 168 | | 122,875 | 694 | | 500 | 137,726 |
| *AGRICULTURAL SECTOR* | 5,918 | - | 1,188 | - | 28,890 | - | - | 1,464 | 37,461 |
| Field Operations | | | 616 | | | | | 454 | 1,069 |
| Processing/Other | 5,918 | | 573 | | 28,890 | | | 1,010 | 36,392 |
| *FISHERIES SECTOR* | 374 | - | 759 | - | - | - | - | 183 | 1,316 |
| Large Ships | - | | 617 | | | | | | 617 |
| Collectives/Processing/Other | 374 | | 142 | | | | | 183 | 699 |
| *MILITARY SECTOR* | 18,415 | - | 9,460 | - | 7,379 | - | - | 8,199 | 43,453 |
| Trucks and other Transport | | | 3,085 | | | | | | 3,085 |
| Armaments | | | 101 | | | | | | 101 |
| Air Force | | | 2,060 | | | | | | 2,060 |
| Naval Forces | | | 4,138 | | | | | | 4,138 |
| Military Manufacturing | 401 | | - | | | | | 21 | 422 |
| Buildings and Other | 18,014 | | 76 | | 7,379 | | | 8,178 | 33,647 |
| *PUBLIC/COMMERCIAL SECTORS* | 17,836 | | 437 | | 5,351 | | 1,307 | 4,603 | 29,534 |
| *NON-SPECIFIED/OTHER SECTORS* | | | - | | | | - | | - |
| *NON-ENERGY USE* | 1,014 | | 866 | | 6,000 | | | | 7,879 |
| *Electricity Gen. (Gross TWhe)* | 3.13 | | 0.32 | 11.91 | | | | | 15.36 |

**Note: Gross terawatt-hours for coal-fired plants includes output for plants co-fired with coal and heavy fuel oil.*

# 3 IDENTIFYING VULNERABLE POPULATIONS, BRITTLE SECTORS, DEFICIT REGIONS, UNANTICIPATED SHOCKS

Within this absolute and relative scarcity exist North Koreans. At a low level of resolution, it is possible to identify key segments of the population that are vulnerable to further loss of energy services; sectors of the energy economy that are particularly brittle, that is, sensitive to reduced or discontinued energy supply either directly or in embodied inputs to their own activities; and regions that could face additional shortfalls in a protracted emergency or post-war context.

The season during which relief and reconstruction is undertaken has a major impact on these pathways. In mid-summer and fall, for example, diesel and power for harvesting and food processing often run out whereas in mid-winter, power supply is often crippled by lack of stored water to run hydroelectric generation, and the population must endure extreme cold.

### 3.1 Vulnerable Populations:

The DPRK population is divided in many ways. Almost all, except for the super-elite, are relatively poor and hungry on a given day. Of concern for this analysis are populations that already suffer from energy-induced poverty, and for whom further deprivation could threaten immediate survival. These segments include:

a) Inhabitants of the prison camps;

b) Women, children, and old people, especially those who are already malnourished or sick in hospitals or clinics, orphanages, nurseries, and other institutions.

c) Residents of provincial cities, especially in the south, that have no access to forests or mountains to forage, no access to coastal fisheries, and for whom the distribution system is mostly already broken.

### 3.2 Brittle Sectors:

Using standard indicators of energy system resilience and energy security, the following sectors are examples of sectors that are brittle (the antithesis of resilient, that is, capable of absorbing and recovering from shocks)[8] and insecure (across a range of economic, social, cultural, geopolitical, and technological criteria).[9] Indicative brittle sectors that could require prior needs analysis and early attention in relief and reconstruction operations are:

a) Agricultural production, especially at time of harvest in the late summer, and related food processing, storage, transport, and distribution systems.

b) Sewage treatment in major cities where plants depend on electricity and chemical supplies, and failure to treat results in mixing of sewage and drinking water with pervasive public health impacts (as occurred in Pyongyang and Nampo in the 1990s);

c) Public transport via trains, buses, subways, and trucks will likely cease at a time when millions of Koreans will be seeking to return to home or to unify their separated families. Creative solutions might ameliorate the urgency, using techniques such as virtual reunion and contact.

d) Telecommunications using cell phones (of which there are an estimated two-plus million in use in the DPRK as of this writing[10]) may prove brittle due to loss of broadcast towers and repeaters, as well as lack of power to recharge cell phones. This may be a critical aspect of maintaining order and establishing civilian control and stable local governance.

e) Coal production, processing, and distribution are already unreliable due to lack of parts and materials such as steel, electricity supplies and safety equipment for mining, and the lack of reliability of trains to move bulk coal. In the winter, coal is critically important for cooking and heating in households in almost all urban and a substantial fraction of rural households.

f) Mineral exports are one of the few legitimate export industries that can help to pay for reconstruction. Mines, processing plants, railways, and ports infrastructure are all brittle, with perhaps a very few exceptions where infrastructure has been augmented by recent Chinese investment. Priorities should be set as to which of these facilities would be worthy of early attention, and which were always uneconomic.

e) Electricity in buildings, especially at night in homes, is already at a minimum level in much of the DPRK, much of the time. Based on household analysis, strategies to provide survivals levels of night light (LED bulbs, candles, compact fluorescent lamps, and others, possibly extending the distribution of solar PV systems already beginning in the DPRK) need to be developed.

### 3.3 Deficit Regions:

A third way to identify possible strategic priorities is to map the geographic pattern of the poorest populations in the DPRK. Generally, the Northeast mountain areas contain large numbers of very poor North Koreans. These data may be analyzed in relation to what is known about energy supply and demand in the DPRK to determine what region-specific energy relief and reconstruction may be required. Modeling at the regional level in disaggregated provincial supply-demand matrices, however, will likely be very difficult, if not impossible in the short-term, and would be of limited utility in any case for what is necessarily a flexible and adaptive strategy that must be guided by major contingencies rather than detailed prior allocation of effort in relation to location of need.

### 3.4 Unanticipated Shocks:

The energy system in the DPRK has the potential to pose systematic shocks via networks collapsing in ways that may amplify greatly the urgency and scale of energy needs. Examples of such shocks include the possibility that China might cut off all crude and refined oil exports to the DPRK, the possible collapse of the power distribution systems around major cities including Pyongyang in a protracted cold period in winter, uncontrolled forest fires that could decimate local biomass for energy services needed for survival in rural communities, and pandemics that arise from concatenating system failures. If relief and recovery in the DPRK was concurrent with major damages in the ROK as a result of a conflict, then international resources may be doubly stressed and should be sized and prepared with both contingencies in mind.

Despite the uncertainties identified above, energy profiles of "illustrative"[11] vulnerable populations, brittle sectors, deficit regions, and possible shocks could be developed for use in pathway analysis, as well as to guide development of strategic delivery options for the recovery phase and to set priorities for early reconstruction. At this stage, we can provide a very rough benchmark estimate of the daily per capita survival energy needs for cooking and heating as 40 MJ of coal or a combination of commercial fuels useful for those end uses), or probably 1.5 to 2.5 times as much biomass fuel. This per-capita fuel use amounts to about 90,000 TJ or 2 million tonnes of oil equivalent (TOE) for a 3 month energy survival (mid-winter) crisis for the nation as a whole, or about 12,000 TJ or 300,000 TOE to serve the urban population of Pyongyang for the winter. In addition, we very roughly estimate that about 65,000 tonnes of motor fuel would be required for survival-level movement of goods (especially food) and people nationally for a 3-month winter period, or about 9,000 tonnes of motor fuel per season for Pyongyang.

## 4 Defining Baseline Path and Variants

This paper outlines issues associated with providing rapid relief and reconstruction for the provision of energy services in the event that energy supplies are interrupted due to partial energy system failure, to collapse of the DPRK central political system, or to outright war. As we noted earlier, our primary focus is on the first contingency, which would lead to a large-scale, complex humanitarian emergency due in part to failure to deliver essential energy services.

Such an energy humanitarian crisis could arise in either mid-winter or mid-summer as two extreme defining circumstances that would shape the ensuing energy crisis, and in each case, the pathway has two phases. The first is immediate emergency relief (time zero to 12 months after the precipitating event). The second is the reconstruction phase that would commence in approximately one year, at which time it is assumed that reconstruction becomes integrated increasingly into inter-Korean and regional energy development planning and national economic decision-making, depending on which contingency drives the energy crisis in the DPRK.

Each of these parameters may be varied, but they combine to form a fundamental matrix of possible outcomes for which US and ROK agencies and the international community need to anticipate desperate needs, emerging developmental priorities, and overwhelming humanitarian imperatives to attend to provision of energy services. These pathway variants serve as the basis for developing relief and reconstruction strategies that will deliver energy services to the most vulnerable populations, to brittle economic sectors, and to energy-deficit regions across these pathways, and also be maximally resilient against the impacts of major unanticipated but inevitable energy shocks concurrent with the defining circumstances. To the extent that energy scarcity impinges on the ability of North Koreans to survive, ensuring that humanitarian energy assistance is available also bears directly on the realization of basic human rights in the DPRK.

Following the above, and based, for example, on an updated version of the existing business-as-usual DPRK energy pathway analysis from Nautilus' prior work, semi-quantitative pathways could be developed for these energy system collapse scenarios for specified dates in the near future. Focusing on the partial but large-scale energy system failure, the humanitarian energy relief scenario should be evaluated in two variants, one starting mid-winter, and one starting mid-summer, each lasting for one year. Such an analysis would seek to capture the effects of seasonality that will affect emergency energy needs during the relief phase, and will better reflect the necessary detail in this short-term scenario. Analysis of the reconstruction scenario would begin where the relief analysis leaves off, and could run into the medium-term, for example, nine years; that is, relief plus reconstruction pathways run for a full decade, reflecting the necessarily continuing and enduring nature of the activities and infrastructure provision that will be parts of the reconstruction effort, in response to what by then would have become a complex, protracted security crisis.

## 5 Strategies for Rapid Relief and Reconstruction

### 5.1 Energy Relief Strategies

Based on the DPRK energy database and other in-depth studies, illustrative profiles of vulnerable energy end users can be produced. These may include, for example, sketches of the energy needs of rural villages,[12] of provincial city household, of prison camps, and of large public welfare buildings such as hospitals. Based on these illustrative energy profiles, estimates in each case of energy scarcity can be applied based on the relief scenario. For each illustrative type, estimates would be made of the number and distribution of similar situations in the DPRK, the number of stressed entities similar to each illustrative type, and the quantity and type of emergency fuel and equipment needed in total. From this analysis, generic strategies can be devised to provide emergency relief given the energy profiles of each of the vulnerable populations, brittle sectors, and deficit regions. This approach permits the preparation of a working estimate of the scale of energy relief that may be required, and identification of the possible strategies to best deliver emergency energy services, which in turn would enable the international community (the ROK, the US, and other allies and partners) to develop organizational strategies, cost estimates, and fuels and materials stockpiling requirements, and even to exercise the strategy both conceptually and in field exercises.

Separately, robust strategies to respond to unanticipated energy systemic shocks can be developed to adapt to disruption induced into relief strategies by such shocks.

A list of indicative energy relief strategies, each of which needs to carefully examine the impact of seasonality, includes:

### Power Sector

- Construct or repair mini-grids, including both existing DPRK grids, and new parallel/separate grids for specific high priority sites such as refugee camps, large public housing or welfare buildings, communications centers, and other areas of critical electricity needs.
- Anticipate and locate existing backup generators to ensure their use does not deplete scarce diesel stocks needed in higher priority sectors (such as agriculture); if necessary, such units should be commandeered for redeployment.
- Stockpile, purchase, commandeer, deliver, fuel, maintain, and secure standby generator sets for high priority relief groups.
- Repair and refurbish existing power generation, transmission and distribution infrastructure, but only where economic or where overriding humanitarian considerations exist.
- Support provision and operation of generation sets to enable early reopening of mines wherever possible (and where local work conditions permit) so as to enable the production of coal for domestic use and of metals and mineral products to help generate income to pay for needed infrastructure and other goods and services.
- Identify highly sensitive, brittle public and private end users with major energy sensitivity, such as urban sewage plants, where provision of power in a timely fashion may avoid major public health crisis or pandemics.

### Institutional

- Provide mobile repair teams to inventory and then engage DPRK technical and line agency personnel in the energy sector. DPRK technicians are skilled in operating under DPRK extreme conditions and in developing improvised solutions to constant failure of the energy systems.
- Deploy critical infrastructure security forces as needed given security conditions.
- Provide technical assistance to DPRK line agency personnel to anticipate emergencies, design and implement improvised solutions in the primary energy supply and transformation sectors (for example, provide coal mine safety kits—methane gas sensors in particular), and in brittle/key end use sectors (such as food processing and distribution).

### Fuel Stocks

- Establish control and security of stockpiles and organize delivery of emergency fuels in locations accessible to vulnerable populations, brittle sectors, and deficit regions:
    - Solid and gaseous fuels for household cooking (especially in port cities where barged gas (liquefied petroleum gas, or LPG) tanks might be introduced as dispensing centers for bottled gas for cooking)
    - Household cooking kerosene stoves and kerosene for refugees, prison camps, and homeless (such stoves may have to introduced from China)
    - Diesel fuel for essential public transport

- ❍ Diesel fuel for backup generator sets for public welfare buildings
- ❍ Diesel fuel to get coal from small mines to users in rural areas (often using tractors towing trailers)
- ❍ Biomass fuels require strategies that enable local communities to avoid further stripping of existing biomass that leads to erosion, floods, soil fertility loss, and other impacts, especially on steep slopes, as well as loss of nutrients otherwise recycled into agricultural production from agricultural wastes.

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**Households (other than fuel provision above)**

- Rapid wintertime insulation delivery and installation in major cities (insulation would likely be imported from China overland of via ports, or possibly from ROK) involving training and employing some of the large numbers of people who would find themselves unemployed or underemployed in the event of a crisis. In fact, reportedly, unemployment and underemployment are already problems in the DPRK today.
- Provision of emergency night lighting, LEDs (Light emitting diodes), CFLs (compact fluorescent bulbs), and candles, both as security measures and to provide basic humanitarian services. Kerosene lamps may be offered where kerosene stoves are deployed on an emergency basis for heating and cooking.
- Water purification systems powered by renewable energy sources, and emergency drinking water kits may be needed where sewage and/or water treatment systems have failed due to power losses in cities.

**Community**

- Early provision of Internet and mobile phone access points using renewable or diesel-powered electricity sources with battery storage.
- Provision of fuel and electricity to clinics for maintenance of medicines and sterilization of medical instruments at the facility level (many technical options are possible).

**Energy Security and Informal Distribution**

The sudden shortage of refined products would create a powerful incentive to commandeer and privatize existing oil stockpiles and distribution infrastructure, including the oil refineries and related flows of crude oil imports, if these in fact continue after a collapse or conflict. Anticipating and establishing control over these "informal" stocks and flows will be critical to the ability of DPRK and external emergency energy relief organizations to operate to support large-scale energy relief operations.

**"Logistical Tail"**

The provision of fuel will in itself entail using fuel, as well as overcoming logistical bottlenecks in fuel provision and distribution. The process of developing and assessing the implications for fuel logistics of relief strategies would therefore include preparing estimates of fuel costs and delivery requirements for fuel to meet the needs identified through the analysis described above. Analysis of the logistical tail would include analysis of possible road-based tanker and rail transport from the ROK, delivery of refined product, bottled LPG, kerosene and LPG stoves, provision of coal via ship, rail and road, and, to a minor extent, air delivery of fuel and energy infrastructure for extreme emergencies or to support relief personnel. Fuel logistics requirements can be estimated based on distance required for delivery and return, fuel cost per unit distance, the types of delivery vehicles employed, and the time needed for travel from fuel sources to distribution center, as well as from distribution centers to end users.

Based on the generic energy profiles of vulnerable populations, brittle sectors, and deficit regions, and in light of possible systemic energy shocks in relief conditions, a key analytical undertaking, as noted above, is to define and develop a set of energy relief strategies that would meet potential demand for emergency energy services in the relief pathways, with sequencing depending in part on seasonality. This analysis would include estimating fuel logistics requirements (delivery systems and fuel usage) and examining how they might be met to deliver the relief fuel to users. A number of agencies active in the Northeast Asia region have longstanding expertise that could be drawn upon for this analysis and planning, including United Nations relief agencies, the World Food program, the ROK and U.S. armed forces, and others. Chinese and Russian energy agencies also have substantial data on the cost and technical aspects of cross-border flows of oil and coal that may be critical in planning a rapid-response energy "surge" to meet energy services needs in the DPRK.

### 5.2 Energy Reconstruction

The fundamental principle in approaching the task of energy reconstruction in the DPRK is to move deliberately, guided by economics based on border prices, recognizing the distortion induced by extreme scarcity at the outset and the importance of keeping open options. In general, this principle means avoiding premature commitment to refurbishing existing energy supply assets, many of which are uneconomic and should be scrapped, and/or serve industrial end-uses that are uneconomic (based, for example, on the needs of the DPRK's pre-1990 economy, which was designed in part to serve and be served by Soviet markets) and should be shut down. A new and modern developmental strategy for the DPRK, especially (and ideally) based on principles of sustainable development, likely will reshape the urban-industrial geography in substantial ways, and the replacement of energy infrastructure should derive from a new, overarching design, and not be predetermined by the desire to refurbish existing facilities independent of their future value. Although substantial ROKG work has been undertaken in many sectors to anticipate the shape of future DPRK infrastructure (for example, the proposed "H" structure of energy, industrial, transport infrastructure—with corridors running up the East and West coasts of the DPRK, and across the DPRK from East to West, as suggested by an ROK infrastructure expert[13]), most of the macroeconomic policy work that will determine these outcomes will not be undertaken until inter-Korean rapprochement or, less likely, the post-collapse or post-conflict decision-making are well underway.

It should be noted that "economic" in the DPRK case currently does, and will at least initially in a relief/reconstruction period, mean something different than in a typical international setting. For example, it may be expensive to run a local power plant, but if the immediate alternative is reliance on diesel-fired power systems, and diesel fuel is unavailable, the local alternative may be the only choice. It is likely that over time, during and following reconstruction, the meaning of "economic" in the DPRK will converge on the more conventional sense of the term, but it is important to be recognize that for a period of time during reconstruction the definition of what is and is not economic for the DPRK will not necessarily be clear.

Nonetheless, it is already possible to outline basic approaches to energy reconstruction in the DPRK. A first approach recognizes that in virtually all supply and end-use sectors, transformation and end use of fuels is vastly wasteful. Almost always, it will be most economical to make existing infrastructure—if it works—more efficient than to supply new infrastructure. A second approach is to only refurbish those elements in the power sector that serve either necessary survival needs of the populace, especially in the cities, or the relatively small number of end users that are economic in their operations. A substantial fraction—likely more than half—of DPRK commercial and industrial end users of power are likely to be closed early in reconstruction due to their fundamentally uneconomic nature. (This principle may be traded against the strong need to employ people in the short-term, but energy refurbishment resources still need to be invested where they are most needed or have the highest social payoff, given the scarcity and suppressed demand that exists and will be expressed in when fuels become available).  An immediate tradeoff may be needed to maintain home and public building heating in winter from waste heat generated at otherwise obsolete, inefficient power plants that are extremely polluting. Survival may require that these plants continue to operate throughout the relief period, at least in winter-time.

A third approach is to upgrade quickly the occupational health and safety of coal mine operations. These mines are believed to be very hazardous and possibly operated by prison and semi-corvée (forced) labor. Extraordinary efforts to substitute non-coal energy resources at the time of maximum need may be obligatory, as whichever agency or coalition of agencies organizing and providing reconstruction efforts will not wish to continue coal mines effectively run as forced labor sites. Determining which mines are safe, and which mines have work practices consistent with the social and cultural standards of the international community, will be a critically important task by which those providing relief and reconstruction aid will be judged by local populations; and it will be essential to obtain the DPRK's official cooperation in upgrading such labor practices, likely with concurrent provision of the missing materiel needed to improve the operational practices at DPRK energy production sites.

The fourth approach recognizes that many of the small hydro-electric plants constructed in the DPRK in the last decade or two are likely to have been uneconomic from the outset, having been built, in many cases, by rural communities in response to party directives. Many of these small hydro plants are not working. Due to the ideological and political origins of some of these plants, great care must be taken to determine which plants are usable and economic, and which should be abandoned quickly even if they work to a limited extent.

Large hydroelectric plants will continue to be a mainstay of the DPRK power system for at least several years following reconstruction, but many large plants are very old, and will need significant refurbishing, as well as stringent safety reviews to avoid, for example, the highly undesirable outcome of downstream populations being endangered due to dams that could fail under the watch of those organizing and providing relief and reconstruction.

A reconstruction strategy should start with the seven basic energy options defined previously by Nautilus Institute, and outlined below. These range from immediate, low-risk, often low-cost steps such as human capacity-building, local pilot projects with humanitarian or economic components, and direct fuels provision, to more substantial national projects such as power system redevelopment, to even more wide-ranging possibilities involving regional cooperation. These options need to be refined and concretized in the qualitative and quantitative pathway analysis, and should form the basis for early discussions between DPRK energy officials and the ROKG and ROK forces as to reconstruction energy priorities for a cooperative humanitarian response to partial energy system failure, given the need to stabilize energy supply, create new civilian and democratic energy governance in the DPRK, and to deliver affordable and equitable energy services to the population.

In summary, these options include:

- **Assistance for policy and legal reforms to stimulate and sustain energy sector reconstruction**. Reform of energy pricing practices, development of energy markets, and capacity-building for careful planning that would allow aid to be based on need and rational objectives are all critical areas for assistance. Additional measures could include training for all energy sector actors, strengthening and developing regulatory agencies and educational/research institutions in the DPRK, and involving the international business community in energy sector investments and technology transfer. Obviously, these tasks will likely be led by the ROKG early in a reconstruction phase, but initial steps during relief and the first year of reconstruction may benefit from substantial technical assistance from the international community, including from the US-DOD.

- **Rebuilding of the electricity transmission and distribution (T&D) system**. An important first step would be to start working with North Korean engineers to identify and prioritize a list of transmission and distribution sector improvements, and to provide limited funding for pilot installations in defined geographic areas that prefigure the principles on which the whole system will be reconstructed. These principles could, and should, include such elements as "smart grids" integrating demand responsiveness and demand control with access to the grid for distributed generation and new central-station renewable energy, as well as conventional power plants.
- **Rehabilitation of power plants and other coal-using infrastructure**. An initial focus should be on improvements in small, medium, and district heating boilers for humanitarian end-uses such as providing heat to residential areas as well as small institutions such as schools and hospitals—although, as noted above, in the medium-term replacement of those boilers with entirely redesigned heat supply and heat demand systems may well be in order.
- **Rehabilitation of coal supply and transport systems**. Coal sector rehabilitation for those mines judged to be economic will require the building or rebuilding of basic systems in mines for ventilation, light, and motive power for the pumping of water and extraction of coal, as well as improvements in safety. Even if most coal in the North proves to be uneconomic, in the short-term, continued operation of at least some of the mines is inevitable.
- **Development of alternative small-scale energy sources and implementation of efficiency measures**. The North Koreans have expressed a keen interest in renewable energy and energy efficiency technologies. In part, this was driven by *juche* ideology and was wholly uneconomic and impractical in the DPRK, which is why there is limited effective renewable energy capacity in the DPRK at present (with the exception of large hydroelectric power plants and, of course, direct biomass energy use). Nonetheless, in some contexts, renewables are fast, small and cheap, and initially emphasize agricultural and humanitarian applications. Applicable strategies in this category include the provision of technical and institutional assistance in implementing efficiency measures, and cooperation in technology transfer for renewable energy and efficiency applications. Focusing on efficiency through regional cooperation could provide the North with access to products, materials and parts. Assistance should also include sector-based implementation of efficiency measures and demonstration projects.
- **Rehabilitation of rural infrastructure**. The goal of a rural energy rehabilitation program would be to provide the modern energy inputs necessary to allow North Korean agriculture to achieve a sustainable production level on a commercial basis, and to meet the basic needs of the rural population. Not to be overlooked in this regard are facilities for food storage and transport, as a significant fraction of the DPRK's harvest reportedly spoils before it can reach consumers.
- **Begin transition to Liquid Petroleum Gas (LPG) networks**. Although LPG as a fuel is more expensive than natural gas, the infrastructure to import LPG, relative to liquefied natural gas (LNG) is much easier, quicker, and less expensive to develop, and allows imports in smaller quantities. LPG is also clean burning, has limited potential to be diverted for military uses, and local piped distribution networks designed to carry LPG can be a first step in any future transition to the use of natural gas.

- **Support the Investigation of Regional Energy Systems**. Investigation and discussions between the potential partners in energy resources sharing—most prominently, international pipelines and power lines—in the Northeast Asia region have been ongoing, albeit in fits and starts, for most of two decades. Ultimately, natural gas pipelines and/or LNG terminals, shared with neighboring countries, can serve as a step toward economic development coupled with regional energy system integration. In addition to these benefits, the potential role of regional energy cooperation in addressing the North's needs and helping to build a peaceful economy has long been recognized. Such projects could potentially provide energy (electricity, gas, oil) as well as a source of income for the DPRK from hosting energy facilities. Also, regional connections--whether in the form of infrastructure or in the organizations needed to administer projects—can provide venues for engaging the North. For example, if a power line is built to transmit electricity from hydro, coal, or nuclear plants in the Russian Far East to consumers in South Korea, the interim Northern power authorities will need to coordinate and establish consistent technical standards, as well as operations and maintenance protocols, to allow the safe and smooth operation and administration of the interconnection.

The pathway for the reconstruction phase of the DPRK's energy economy envisioned in this study must account for a number of key domestic institutional obstacles and issues. (External donor and humanitarian energy supplier coordination is a separate set of constraints that must be addressed for an effective response, but is not analyzed here.) These are:

a) Since there is a suppressed, latent demand for energy services, as infrastructure is rebuilt, the DPRK electricity system and other fuel supply infrastructure will need to accommodate a surge in demand. As a result, measures such as energy efficiency improvements will not appear as effective as anticipated, at least over the DPRK society as a whole (as opposed to in individual installations), because a significant portion of the energy saved will be absorbed by previously latent demand.

b) Compounding the risk of a surge in the use of energy services is the virtual lack of energy product markets. Without fuel pricing reforms, there will be few incentives for households and other energy users to adopt efficiency measures or otherwise control their fuel consumption. There will also be no guarantee that generators, coal mines, and other fuel suppliers will recover sufficient funds through sales to cover production costs, let alone to reinvest in the further expansion of supply or other upgrades.

c) Implementing improvements in the energy sector will require building human capacity. Most North Koreans have a strong general education, but decades of relative isolation have made human capacity scarce in fields such as advanced science and engineering, economics and finance, regulation, and policy development.

d) Shortcomings in institutional capacity also pose an important challenge. Because of the North's political structure, only a limited number of officials come into contact with foreigners. To the extent that reconstruction relies upon pre-existing institutional and social capacity, these limits constrain the number of projects that the North can be involved in at any given time in a post-conflict situation. It will be critical to overcome the effects of past compartmentalization of the North's dealings with foreigners to ensure that outsiders can coordinate projects and to work with the appropriate counterparts in the DPRK without obstruction.

e) Reconstruction of the DPRK's energy economy will be cost an enormous amount—on the order of $100 billion for the power sector alone over at least a decade. An international consortium will be necessary to mobilize these resources, and a significant fraction of the investment will come via private financial markets, as well as will be administered via international agencies such as the World Bank. Coordination and communication between international and ROKG agencies involved in the immediate relief and on-going reconstruction of the energy sector must be achieved, not left to evolve on an *ad hoc* basis.

The above implies that a key element of reconstruction planning, ideally to be undertaken collaboratively by national and international agencies likely to be involved in the reconstruction effort, will be to develop a set of strategic options for reconstruction of the DPRK's energy economy, starting with the existing set outlined above, and to define and develop quantitative and qualitative attributes, including scale, cost, and sequencing, of each option.

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# III. References

[1] See United Nations, Interagency Standing Committee, *Civil-Military Guidelines and Reference for Complex Emergencies*, UN Office for the Coordination of Humanitarian Affairs, New York, 2008, at: https://docs.unocha.org/sites/dms/Documents/ENGLISH%20VERSION%20Guidelines%20for%20Complex%20Emergencies.pdf; The Sphere Project, IFRC et al, *Humanitarian Charter and Minimum Standards in Humanitarian Response*, Practical Action Publishing, 2011, at: http://www.sphereproject.org/handbook/

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[2] See *Energy for the Warfighter, Operational Energy Strategy*, US Department of Defense, 2011, at: http://breakingenergy.com/documents/energy-for-the-warfighter-the-militarys-operational-energy-str/;

US Joint Forces Command, *Handbook for Military Support to Essential Services and Critical Infrastructure*, Unified Action Handbook Series Book 2, February 2, 2010, at: www.dtic.mil/doctrine/doctrine/jwfc/esci_hbk.pdf; and

D. Brinkerhoff *et al, Guide to Rebuilding Public Sector Services in Stability Operations: A Role for the Military,* Brigham Young University, October 2009, at: http://www.strategicstudiesinstitute.army.mil/pubs/display.cfm?pubID=945.

[3] The phases of conflict management used by the DOD in planning are Phase 0, shape the potential conflict, Phase 1, Deter potential adversaries, Phase 2, seize the initiative, Phase 3, dominate, Phase 4, stabilize, including ensuring the provision of essential services, and Phase 5, enable civil authority, including enabling the provision of essential services. We refer to these phases below. Most of the analyses described in this paper are designed to address phases 4 and 5, though the outputs of the type of detailed analysis that might build on the concepts discussed below are also

likely to have lessons for phases 0 and 1 of management of a conflict involving the DPRK.

[4] See the reports for these projects at: https://nautilus.org/projects/by-name/asian-energy-security/ and at: https://nautilus.org/projects/by-name/dprk-energy/

[5] "*Forget linearity.* Planned or logical sequencing will almost always be disrupted by the unpredictability of activities on the ground. Asynchronicity is the rule, not the exception. Since S&R missions do not unfold with any linear logical process, the need for a strategic vision and direction towards that vision is crucial." United States Army Peacekeeping and Stability Operations Institute, *Guiding Principles for Stabilization and Reconstruction*, US Institute of Peace, Washington DC, 2009, p. 5-32, at: http://www.usip.org/sites/default/files/guiding_principles_full.pdf.

[6] See, for example, David F. von Hippel and Peter Hayes, *An Updated Summary of Energy Supply and Demand in The Democratic People's Republic Of Korea (DPRK)*, published as Hanyang University Center for Energy Governance and Security Working Paper 2014-2, and available from http://www.egskorea.org/sub/sub2_2.asp and as https://nautilus.org/napsnet/napsnet-specia--reports/an-updated-summary-of-energy-supply-and-demand-in-the-democratic-peopl-s-republic-of-korea-dprk/

[7] See, for example, David F. von Hippel and Peter Hayes (2014), "Private Purchases of Solar Photovoltaic Panels in the DPRK: Signs of Green Growth on the Way?", Hanyang University Center for Center for Energy Governance & Security *Global Energy Monitor* Vol.2, No.9, 2014-11, available from http://www.egskorea.org/sub/sub2_1.asp.

[8] Indicators of structural brittleness at a sectoral or sub-sectoral level are simply the inverse of resilience indicators. Typical indicators for energy infrastructure resilience include: statistical probability of supply interruption in network industries; expected number of hours in which energy is unserved; value/level of unserved energy; energy storage capacity and/or stocks by fuel and market; largest single source of supply in a market energy economy, and redundancy in network architecture. Typical indicators for resilience for energy users include: energy demand level, energy intensity, energy costs, and back-up arrangements for energy-sensitive users, for example, hospitals, clinics, and banks. Source: M. Chaudry et al, *Building a Resilient UK Energy System,* Research Report, ref UKER/RR/HQ/2011/001, 14 April 2011, pp 14-15, at: http://nora.nerc.ac.uk/16650/1/UKERC_energy_2050_resilience_WP2009.pdf

[9] D. von Hippel *et al,* "Evaluating The Energy Security Impacts Of Energy Policies," in B. Sovacool, editor, *Routledge Handbook of Energy Security,* Routledge, 2011.

[10] See, for example, Martyn Williams (2014), "Koryolink subscriptions hit 2.4 million", in *North Korea Tech*, available as http://www.northkoreatech.org/2014/09/08/koryolink-subscriptions-hit-2-4-million/.

[11] Here illustrative means conceptual in nature, not a best or worst case.

[12] See *Rural Energy Survey in Unhari, DPRK: Methods, Results and Implications*, Nautilus Institute Special Report, May 20, 2001, at: http://www.academia.edu/1322357/RURAL_ENERGY_SURVEY_IN_UNHARI_VILLAGE_THE_DEMOCRATIC_PEOPLES_REPUBLIC_OF_KOREA_DPRK_METHODS_RESULTS_AND

[13] ROK thinking about the future urban-industrial development pattern of the DPRK in an "H" concept is described by Won Bae Kim, The basic H-design "is composed of four corners (six later) and three transport axes (east, west, and horizontal) to lift up the North Korean economy and

connect to the regional economies of NEA." It has "six pockets of growth points to push the economy forward." It has 3 phases: "1st phase: four corners and partial connection with neighbors; 2nd phase: completion of three axes and six growth points; 3rd phase: completion of networks." The four anchor points are: "Shinuiju, Kaesong, Guemgangsan, and Rason are the four corners where cross-border exchanges have been occurring; these are natural anchor points to lift NK economy in the first stage and they have a special status." Nampo and Wonsan as viewed as the two growth centres: "Nampo: export-processing zone that will be turned into a hi-tech center (esp., environment technology); Wonsan: a center of logistics and shipbuilding in the east sea rim as well as a hinterland city for Guemgang-Seorak international tourist zone." See W.B. Kim, "Design of Infrastructure Development in North Korea: A Practical Approach," presentation at DPRK Energy Experts Working Group, Beijing, May 2008, available as https://nautilus.org/projects/by-name/dpr--energy/2008-meeting/papers-and-presentations/#ixzz2ZGADGhhP.

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