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CONSIDERING POWER SYSTEM PLANNING IN FRAGILE AND CONFLICT STATES

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JEL Classification C6, O2, Q4

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CONSIDERING POWER SYSTEM PLANNING IN FRAGILE AND CONFLICT STATES

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Abstract: Traditional methods of energy planning are likely to provide results that may be inappropriate in fragile and conflict-prone countries. The risks of violence and damage, or significant delays and cancellations in infrastructure development, are rife in these states. Thus, least-cost planning processes must explicitly address the inherent risks. While there are numerous statistical methods for dealing with decision making under uncertainty, few of them have been applied to power system planning and tailored for these situations. We present a general theoretical framing of the issue, and illustrate application of a very simple method to a case study of the Republic of South Sudan. We find that, in general, the resilience aspects, combined with modular and incremental benefits of distributed generation technologies and systems emerge as attractive options if the various risks of infrastructure development are included in modelling techniques.

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1. Introduction

In fragile and conflict-affected country settings, power system planning cannot ignore the inherent risks in infrastructure development. Such risks can, for example, manifest in projects being delayed, abandoned, or coming in at very high costs. Security issues can thus, significantly hamper, or make infeasible, the delivery of power system master plans.[1] Typically, optimization-based planning methodologies do not consider these issues of uncertainty and will choose the economies of scale offered by centralized systems. Yet these are inherently dependent on numerous functioning systems and institutions, as well as some level of "stability" in the surrounding political and social infrastructure that is conspicuous in their absence in many countries. Apropos of that, the core message of the 2011 WDR (World Bank, 2011) states, "strengthening legitimate institutions and governance to provide citizen security, justice, and jobs is crucial to break cycles of violence." Additionally, countries often lack the capacity to absorb and implement these plans even when they are completed in terms of both human capacity. Related, the World Bank Energy Sector Directions Paper (2013) noted that, "Providing electricity may be especially important in fragile and conflict-affected states, where resumption of electricity supply can be important in restoring confidence in the government, strengthening security, and reviving the economy (World Bank Directions Paper, 2013)."

New methods or modifications for explicitly recognizing and internalizing these risks into planning tools are needed so that governments and decision makers can be better informed. This information is also useful in considering alternative, more flexible and incremental steps when making investment decisions for power systems. Some approaches have used "robust decision making" (RDM) techniques which, "helps planners discover strategies that…perform well across a large range of plausible futures (Popper et al., 2009)."[2] As an example, consider energy security in a country like Afghanistan; creating employment in small-scale projects based on grid or mini-grid access as an alternative to diesel generation appears as a useful long-term strategy to deter insurgent attack—a core security issue. Zeriffi et al (2002), make the case clearly, and quantitatively, "…[In] a quantitative comparison of an electricity system based on distributed natural-gas-fired units to a traditional system based on large centralized plant. The distributed system proves to be up to five times less sensitive to measures of systematic attack."

This paper considers how traditional power system planning and expansion models could be refined and/or augmented to better allow for the deep uncertainty associated with development in these fragile or conflict states. Section 2 provides a context of the issue globally. Section 3 considers power system planning under difficult conditions. Section 4 considers some of the possible methodological approaches, while Section 5 provides a case study of the Republic of South Sudan (South Sudan) using one simple approach. Section 6 concludes the discussion highlighting the need for further development of a robust methodology to address planning issues in conflict-prone countries.

[1] One way of categorizing these uncertainties might be: 1) Uncertainty related to smooth implementation of investment's construction plan (longer construction time or even probability of cancelation). 2) Uncertainty related to smooth operation of an investment due to attack/ sabotage. 3) Uncertainty related to load demand, which depends on how quickly the country will recover from unrest.

[2] For more on this type of analysis see also: Lempert et al., 2003, 2006, and 2011; and Bonzaniga and Kalra, 2014.

2. Fragile and Conflict States

About 1.2 billion people live in countries affected by fragility, while about 800 million people live in developing countries with the highest homicides rates (World Bank, 2015). By any measure, the fact that over 2 billion people in the developing world are confronted by some form of extreme violence illustrates the nature of the development challenge: conflict and violence either bar the door to development for many countries or strip-off years of development gains when conflict occurs.[3] If extreme poverty is to be eliminated by 2030, the World Bank Group's own target, it is these countries which need the closest assistance.

The WDR (2011) provides a useful framework for defining the internal and external stresses of conflict (Table 1).

Table 1: Economic, Security and Justice stresses (World Bank, 2011)

Stresses	Internal	External
Security	• Legacies of violence and trauma	• Invasion, occupation • External support for domestic rebels • Cross-border conflict spillovers • Transnational terrorism • International criminal networks
Economic	• Low income levels, low opportunity cost of rebellion • Youth unemployment • Natural resource wealth • Severe corruption • Rapid urbanization	• Price shocks • Climate change
Justice	• Ethnic, religious, or regional competition • Real or perceived discrimination • Human rights abuses	• Perceived global inequity and injustice in the treatment of ethnic or religious groups

Source: WDR team.
Note: This table, although not exhaustive, captures major factors in the academic literature on the causes and correlates of conflict and raised in the WDR consultations and surveys.[33]

A 2015 World Bank Policy Research Paper indicates that the share of global poor living in fragile and conflict affected situations today will at least double by 2030. The 2011 World Development Report suggested the incorporation of adaptable approach to move beyond conflict and fragility and secure development. The World Bank's Fragile, Conflict and Violence Group annually releases the Harmonized List of Fragile Situations (Table 2). The 2016 list shows 29 countries. Of those, South Sudan has the second lowest WB Country Policy and Institutional Assessment (CPIA) score (after Eritrea).

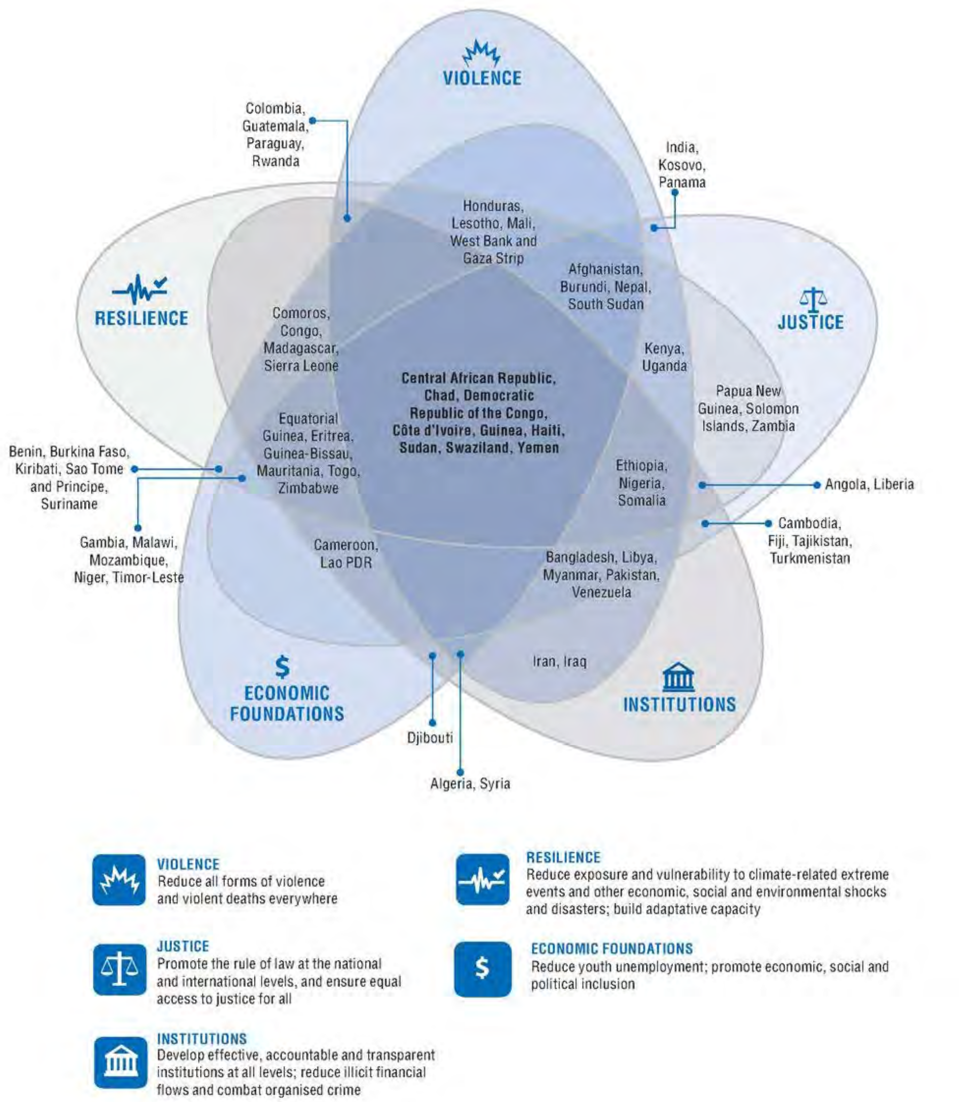
[3] http://www.worldbank.org/en/topic/fragilityconflictviolence

Table 2: Fragile States (World Bank, 2015)

Country	WBG CPIA	AfDB or ASD CPIA	Harmonized Average	Political & Peacebuilding Missions b/	Peace-keeping Missions c/
IDA Eligible					
Afghanistan	2.650	2.800	2.7	P	
Burundi	3.267	3.376	3.3	P	
Central African Republic	2.433	2.283	2.4	P	
Chad	2.692	3.241	3.0		
Comoros	2.717	2.465	2.6		
Congo, Dem. Rep.	2.975	3.299	3.1		PK
Côte d'Ivoire	3.250	3.499	3.4		PK
Eritrea	1.992	2.141	2.1		
Gambia, The	3.142	3.207	3.2		
Guinea Bissau	2.500	2.673	2.6	P	
Haiti	2.858		2.9		PK
Kiribati	2.950	3.050	3.0		
Kosovo	3.550		3.6		PK
Liberia	3.100	3.498	3.3		PK
Madagascar	3.133	3.198	3.2		
Mali	3.367	3.653	3.5		PK
Marshall Islands	2.642	2.900	2.8		
Micronesia, Fed. Sts	2.733	2.950	2.8		
Myanmar	3.050	3.133	3.1		
Sierra Leone	3.267	3.368	3.3	P	
Solomon Islands	2.933	3.308	3.1		
Somalia		1.105	1.1	P	
South Sudan	2.000	2.216	2.1		PK
Sudan	2.425	2.562	2.5		PK
Togo	2.992	3.203	3.1		
Tuvalu	2.792	2.975	2.9		
Yemen, Rep.	2.967		3.0		
Territories					
West Bank & Gaza				P	
Blend					
Timor-Leste	3.058	3.392	3.2		PK
Zimbabwe	2.658	2.207	2.4		

Providing energy services to these areas directly helps focus on some of the key reasons that youth join gang or rebel movements, namely unemployment and idleness (World Bank, 2011). A often overlooked impact of a lack of energy services in fragile and conflict states is highlighted in the WDR (2011): "In international dialogues on food, energy, and climate, fragile states have weak voices despite bearing substantial impacts…Rising global demand for food and energy may impact fragile and violence-affected states severely."

A 2013 IEG report, though, noted that the World Bank "[develop] a more suitable and accurate mechanism to classify fragile and conflict states (FCS)". A 2015 OECD report presents a new, multidimensional monitoring framework which uses five dimensions of fragility based on a post-2015 framework: violence, justice, institutions, economic foundations and resilience (see Figure 1). Sudan sits squarely in the middle of the diagram, and we return to it in the case study later in this paper.



Note: The 9 countries at the centre of this Venn diagram rank among the 50 most vulnerable countries in all 5 fragility clusters simultaneously. Moving out from the centre, those listed in the overlapping areas are among the 50 most affected in four, three and two clusters. The five proposed dimensions are taken from the emerging SDG framework.

Figure 1: Fragile and conflict schematic (OECD, 2013)

Approaches for dealing with and improving the delivery of services such as: nutrition, education, tourism, environment, and trade in conditions of conflict and fragility are all available (see e.g., Baliamoune-Lutz 2009; Karsenty and Ongolo 2012; Novelli, Morgan et al. 2012; Harber 2013; Menashy and Dryden-Peterson 2015; Taylor, Perez-Ferrer et al. 2015). Evans (2015) provides a useful round up of recent thinking in conflict and fragility in Africa under headings including, institutions, trade, and mining and natural resources. Rubaba et al. (2015) consider infrastructure development broadly using the case of DRC. It is also clear that many military and national intelligence services use uncertainty techniques in their infrastructure designs, as do many of the major oil and gas companies. Still, very little of the literature has specifically considered electricity systems expansion in these conditions. As a result, power system planning in these FCS countries rely on deterministic least-cost planning with ‘perfect foresight’, unlike in the advanced electricity markets, where models are often stochastic and reflect some of the economic and policy uncertainties on both costs and prices.

3. Power system planning in fragile states

While power system planning often uses probabilistic methods (see e.g., Pineda, Morales et al. ; Rastgou and Moshtagh 2014; Zhang, Li et al. 2014; Alizadeh and Jadid 2015; Bagheri, Monsef et al. 2015; Georgilakis and Hatziargyriou 2015; Ghasemi, Ghavidel et al. 2015; Hemmati, Hooshmand et al. 2015; López, Pozo et al. 2015; Sarhadi and Amraee 2015; Seddighi and Ahmadi-Javid 2015; Seddighi and Ahmadi-Javid 2015), these concepts are generally not applied for national planning under conditions of the particular and extreme types of stress faced in fragile and conflict environments. Farrell et al. (2004) present a picture of this aspect of energy security. They discuss how the concept of critical infrastructure protection differs from traditional energy security concepts, “Key concepts include redundancy, diversity, resilience, storage, decentralization, and interdependence.” Zerriffi et al. (2007) present a characterization of different types of disruption for power system including conflicts. They categorize various modes of disturbance, their causes, characteristics and likely impacts. Almost all of them are applicable in fragile states, and some explicitly so, such as localized direct conflict damage due to terrorism, civil war, sabotage, or regional insurgency. In most of these cases the likely impacts are similar, resulting in increased failure probabilities and magnitudes.

As noted, it is difficult to adequately represent the constraints and risk profiles of fragile and conflict states. Thus, a typical least-cost plan tends to have a natural bias towards “scale-efficient” solutions such as large-scale centralized projects often ignoring the risk of these projects not being eventuated, or delayed, or damaged for extended periods, or even destroyed. Filters that can provide prioritization of resiliency in the face of the realities of severe security concerns might help refine the methodologies to show very different “optimal” infrastructure outcomes. South Sudan planning offers a good example. Figure 2 depicts reported areas of violence in the country.

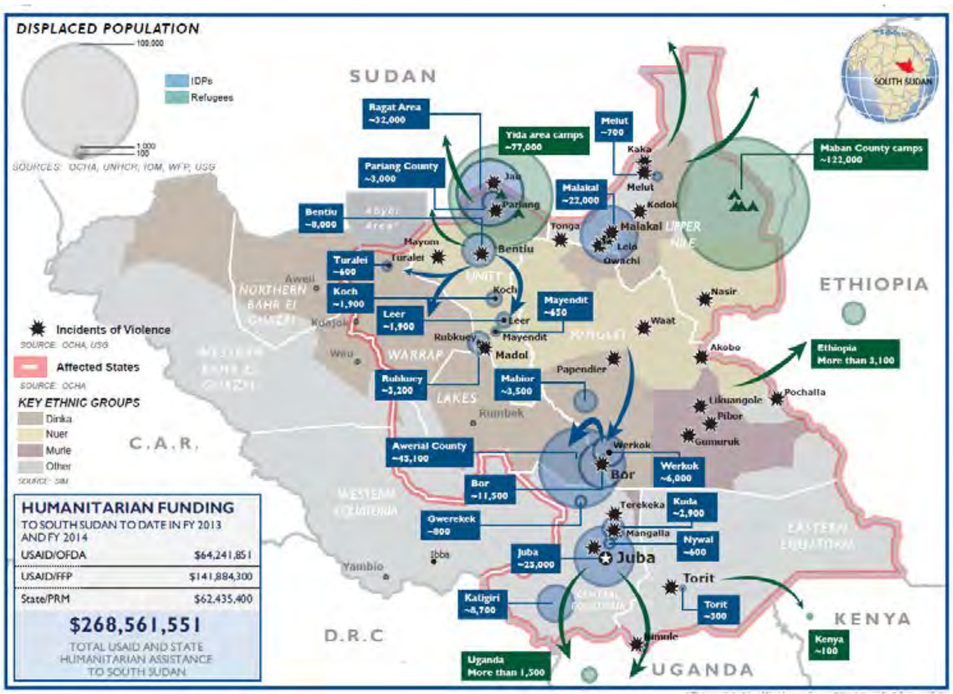


Figure 2: Transmission plan and incidents of violence in South Sudan (USAID, 2013)

Solutions that are modular, flexible, less capital intensive and easier/quicker to build and manage, offer useful attributes in conflict-prone areas. For instance, in a particular scenario, building a large hydro plant may well be the least-cost option under certainty, perfect foresight (i.e., ideal scenario)[4], but if we start to factor in the quantitative impact of the risks that the project may be delayed, or may never happen, or be damaged, the risk-adjusted levelized cost may start rising quickly to a point more distributed[5] choices including mini-grids may work out to be cheaper. Though we cover this in Section 4 in more detail it is important to note that investors will probably adjust its cost or its required rate of return for all these risks, but there is an impact on the country's social welfare that is also important and is difficult to be modeled through the risk-adjusted input costs.

Stand-along systems, like mini-grids, also have the benefit of being able to be engineered to be compatible with the grid if or when it arrives. Distributed systems not only spatially distribute the physical hardware, but also the risk of failure. By contrast, large facilities that benefit from economies of scale are also vulnerable to attack and concentrate risk over a much smaller spatial domain. As a result they are being deployed in military facilities across the United States just for this core benefit in serving critical infrastructure.

Using risk-adjusted rates for a particular project to discriminate it against other projects has its disadvantages, but it is a starting point to bring in the necessary analytical concepts to factor in the risks.

[4] As an example, that in many countries that use WASP ((Wien Automatic System Planning Package) power planning modelling tools—the large hydro projects (both size, timing and amount of storage) are not optimized. Rather, the large hydro generation is imposed exogenously.

[5] We do not define a scale for distributed generation here, as it is a context specific number.

Consider an illustrative example of a scale-efficient Combined Cycle Gas Turbine (CCGT) plant vs. a solar mini-grid in terms of Levelized Cost of Electricity or LCOE (Figure 3). As the figure shows, as we start explicitly imposing the costs typically encountered in a fragile environment associated with higher financing costs (especially for large-scale projects), higher operation and maintenance costs, the 'risk-adjusted' LCOE of a CCGT may exceed that of a solar mini-grid.

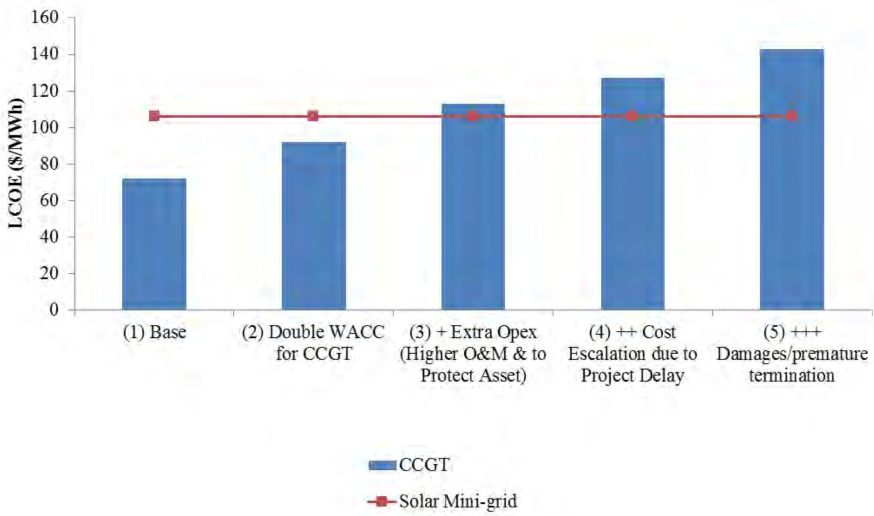


Figure 3: Illustrative LCOE example of centralised vs. mini-grid

Notes:

(1) The following assumptions are used: Base WACC of 10%. Capital cost of CCGT of $1200/kW for a 250 MW unit with a heat rate of 7.2 GJ/MWh, gas price of $7/GJ being utilized on average at 70% capacity factor. This yields a base CCGT LCOE of $72/MWh. Additional operating cost including security costs and substantially higher contractual costs for regular maintenance is expected to add $25,000/MW/year on average based on data obtained from South Sudan diesel plant. It is assumed that a delay in project implementation by 3 years would raise cost of the project by 25% (i.e., average capital cost of the project would rise to $1,500/kW). Damage cost or premature termination is assumed to reduce the technical life by 5 years.

(2) In this example, we have assumed that the solar mini grid LCOE is 10.6 c/kWh using the same base WACC of 10%. Solar mini-grids as distributed resources are unlikely to be impacted the same way as a CCGT, and as such we have assumed the cost and risk profile are not affected by fragility. In reality, these resources may also face some escalation of cost, but an issue that we have ignored for the purposes of illustration.

Although these issues are well understood in qualitative terms and even practiced in the field, there has not been a way to quantitatively formalize this trade-off to produce a power system plan that finds a good balance between cost and risks that characterize the ever changing dynamics of fragile states. Zerrifi et al (2002, 2007) and Salmeron et al (2004) have proposed analytical models that explore some facets of the problem. However, Zerrifi et al (2002) and Salmeron et al (2004) essentially focus on adopting standard power system reliability models and concepts that have distinct focus on purely reliability impacts of damages to the generation/transmission network that may eventuate in a conflict situation. It entails design considerations to make the power system more robust, but does not address the issue of what type/size of investments are more suited considering the trade-off between costs and risks. Zerrifi et al

(2007) is the first step to address this that lays out the benefits of distributed generation (DG) in the context of an environment characterized by significant conflicts. For instance, Zerriffi et al. (2007) lists the 'conflict benefits' of distributed generation. It includes beneficial aspects such as: increased number of smaller sized generators, decreased reliance on centralized T&D, real-time operational advantages, fuel flexibility and increased fuel storage options. Additionally, the goals of the planning exercise can influence design. Powering key cities, or key manufacturing or agricultural lands might help to best "kick start" an economy, or at least provide an initial basis for economic and social development. Finally, it is clear that the States that appear on the "List" are homogenous. As an example, several of them are having success with private sector investment in independent power plants such as: Cote d'Ivoire, Madagascar, and Zimbabwe. In these cases, different approaches may be required. Even in these cases the necessary enabling environments to ensure the sustainability of these private investments is often not fully in place.

Of course we might ask is least-cost planning useful at all in fragile and conflict settings, at least in the most troubled areas. In other words, should this step come in at a later date after the worst of the conflicts have passed and there is a semblance of stability? What we can see in many of these countries and regions, is the large deployment of individual back-up generators. As an example, installed capacity of off-line privately owned petrol and diesel generators in Kabul was estimated at 2,000 MW some years back – four times the capacity it was getting from the interconnected system (Spencer, 2015). Still, the need for planning exists, it just needs to be cognizant of the very different parameters in these contexts. If formal planning is valid (and there is probably a subset of FCS where it is) how should one go about it? As an example, the approach adopted for Afghanistan (three LCPs since 1979) seems not to have worked well. The consultants have not learned from previous efforts and trot out the same projects, based largely on the same guesswork, time and again, with different timetables. Capacity to do this kind of planning is often near-zero in the utilities (even assuming a utility exists) and bringing in a consultant firm seems doomed to fail because of lack of understanding or lack of ownership of the results. Even with a realistic, achievable plan success is far from guaranteed. FCS also suffer another problem, which is that they often have a multitude of donors all wanting to pursue their own agendas. It is clear that there are no shortage of obstacles to overcome.

An initial framework that would link attributes of power investments to the type of uncertainties is presented in Table 3. To illustrate my point, I provide a draft one below. Future research will validate if the attributes are the correct ones and are exhaustive and future research will also try to model the links.

Table 3: Power investment attributes and associated uncertainties (Spyrou, 2015)

Attribute	Uncertainty
Location of the investment	Uncertainty on investment implementation; Probability of being target of an attack (incl. the probability of attack to T&D).
Size of the asset	Size of impact/social welfare loss in case of an attack; probability of attack could also differ based on size Flexibility for adaptation to future stages of development.
Technology of the asset	Construction time differences may slow down or accelerate recovery to peaceful conditions; Prone to different uncertainties related to procurement of fuel or maintenance equipment/replacement parts;

	Flexibility to adapt to future conditions e.g. if a transmission grid has been constructed for HY integration, better prospects for interconnection with neighboring countries or electrification across the country in the future.
Ownership of the asset/financing: public/private	Different risk premiums, budget limits and probably different probabilities to recover the cost of the investment.

4. Possible planning techniques and tools for fragile states

How best can we modify the existing least-cost planning tools that we have? Or, do the situations in fragile and conflict states necessitate a fundamentally new approach? We might be able to use the risk factors identified in Table 2, and link them to specific modelling approaches. Unfortunately, there is no simple answer that will fit all circumstances. As alluded to there is a wide literature on probabilistic methods that might be employed.[6] It is beyond the scope of this paper to comprehensively consider this wide literature. Rather, we briefly describe three possible approaches, and utilise the first in a case study. These approaches are not mutually exclusive and do not have discrete boundaries between them; the final solution/model may be some combination of two or more.

- *Least-cost planning tools with tailored inputs:* Using a standard least-cost planning model, but one that identifies risk premiums as inputs.[7] Assigning risk weightings to cost-of-capital estimates is one way to try and internalize the severe investment risk climates in these countries, but as we have alluded to before it is likely an imperfect proxy. One can also add the cost of protecting the investments to fixed O&M, or the additional construction of building the project as another option. These costs and risk premiums may change over time that may also be simulated as alternative scenarios to test the robustness of these projects. In short, this option can be viewed as an extension of the least-cost planning model but one wherein the planner makes conscious interventions through choice of model inputs. It is probably the most limited of the three options but one that can actually be implemented more readily/easily where the technology choices are relatively limited (e.g., one big centralized generation plant vis-à-vis distributed generation). Another way to think about this is to embed such models into a decision analysis framework, rather than trying to impose "risk premiums". It may also consider the modalities of finance, and in particular the split between debt and equity financing and public versus private funding, and that each of these sub-categories have different risk premiums. A full discussion of how to assign probabilities in a decision analysis framework is beyond the scope of this short paper (See e.g., Spetzler, et al., 1975; Aven, 2007; Keeney, 1982; Howard, 1968)

- *Enhancement of the least cost-planning model with a simulation component:* The second option is to extend the least-cost model to partially reflect some of the idiosyncratic uncertainties, e.g., uncertainties in materializing a large project, or the risk of damages to assets (including generation and transmission towers/sub-stations). This might also include assigning different

[6] Full textbooks have been dedicated to such methods such as Bazilian and Roques, 2008.

[7] Although this is the approach used in the case study later in the paper. We acknowledge the large difficulties and inherent *ad hoc* nature of this approach.

distributions to various core assumptions and using techniques like Monte-Carlo to consider a wider range of possibilities. [8] The modelling techniques for dealing with such uncertainties are not particularly new, although their application for power system planning has been confined to the realm of academic literature and even there the translation of these techniques for fragile state applications is surprisingly rare. Although this would require some changes to the scope and algorithms of traditional least-cost models, it may be worthwhile in cases where the spectrum of generation and transmission investment choices, as well as geographical scope are wider, and the investments at risk are significant enough to warrant a closer inspection of the trade-offs.

- *Stochastic and real-options models:* The third category of tools that are purpose made for such environments and generally fall under the heading of decision-making under uncertainty.[9] Those include methods like stochastic modelling and real options.[10] A significant advantage of the methodology is indeed that one can explicitly capture the flexibility or "option" value of some of the modular generation/transmission investments. For instance, a large number of mini-grids as opposed to a single central solar PV plant may be more expensive, but can offer significantly higher flexibility to mobilize financing, and develop these on "as needed" basis. Further if the technology choices are made in such a way that these can be hooked onto the main grid at a later stage if/when the grid arrives (i.e., are backward compatible), the option value of these investments can enhance greatly. Again, there are a reasonable number of applications of these techniques within the academic domain. However, there is limited practical application of it in the real world—very limited for developing country power systems, and definitely none that deals with fragile state uncertainties. If we add all the efforts starting from creating a reasonable dataset to building and validating a new tool using real option methodology, it is a significant task. That said, if we have a situation where the uncertainties span across multiple large-scale projects possibly across national boundaries and across upstream fuel, generation and transmission, there may well be merit in looking into the prospect of developing one of these tools.

This paper focuses on the first of these approaches in the case study in the next Section. We hope to produce further papers that consider the other two approaches. Figure 4 presents ad illustrative schematic of what a process might look like when using a fragile and conflict state-refined power system planning tool. It posits five steps beginning with a detailed description of the precise risks inherent in the country being considered, moving through an iterative top-down and bottom-up modelling exercise, and into applying one or more of the techniques previously mentioned.

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[8] See e.g., Mavrotas, et al. (2010); Caralis, et al. (2014); Jeon and Shin (2014); Pereira, et al. (2014); Arnold, U. and Ö. Yildiz (2015); Farges, O., J. J. Bézian, et al. (2015). Using a Monte Carlo methodology with metrics of LOLE and LOEE, Zerriffi et al. (2007) find clearly that, "The need for improved electric power systems planning under stress conditions …indicate that system architectures with significant DG could result in improvements in system reliability…The implications for energy policy in less stable locations could not be clearer."

[9] See e.g., Cai, Y. P., G. H. Huang, et al. (2009); Rohlfs, W. and R. Madlener (2013); Soroudi, A. and T. Amraee (2013); Mirakyan, A. and R. De Guio (2015); Scholten, L., N. Schuwirth, et al. (2015).

[10] See e.g., Siddiqui, A. and S.-E. Fleten (2010); Cheng, C.-T., S.-L. Lo, et al. (2011); Fernandes, B., J. Cunha, et al. (2011); Martínez-Ceseña, E. A. and J. Mutale ibid; Santos, L., I. Soares, et al. (2014); Kitapbayev, Y., J. Moriarty, et al. (2015); Wesseh Jr, P. K. and B. Lin (2015).

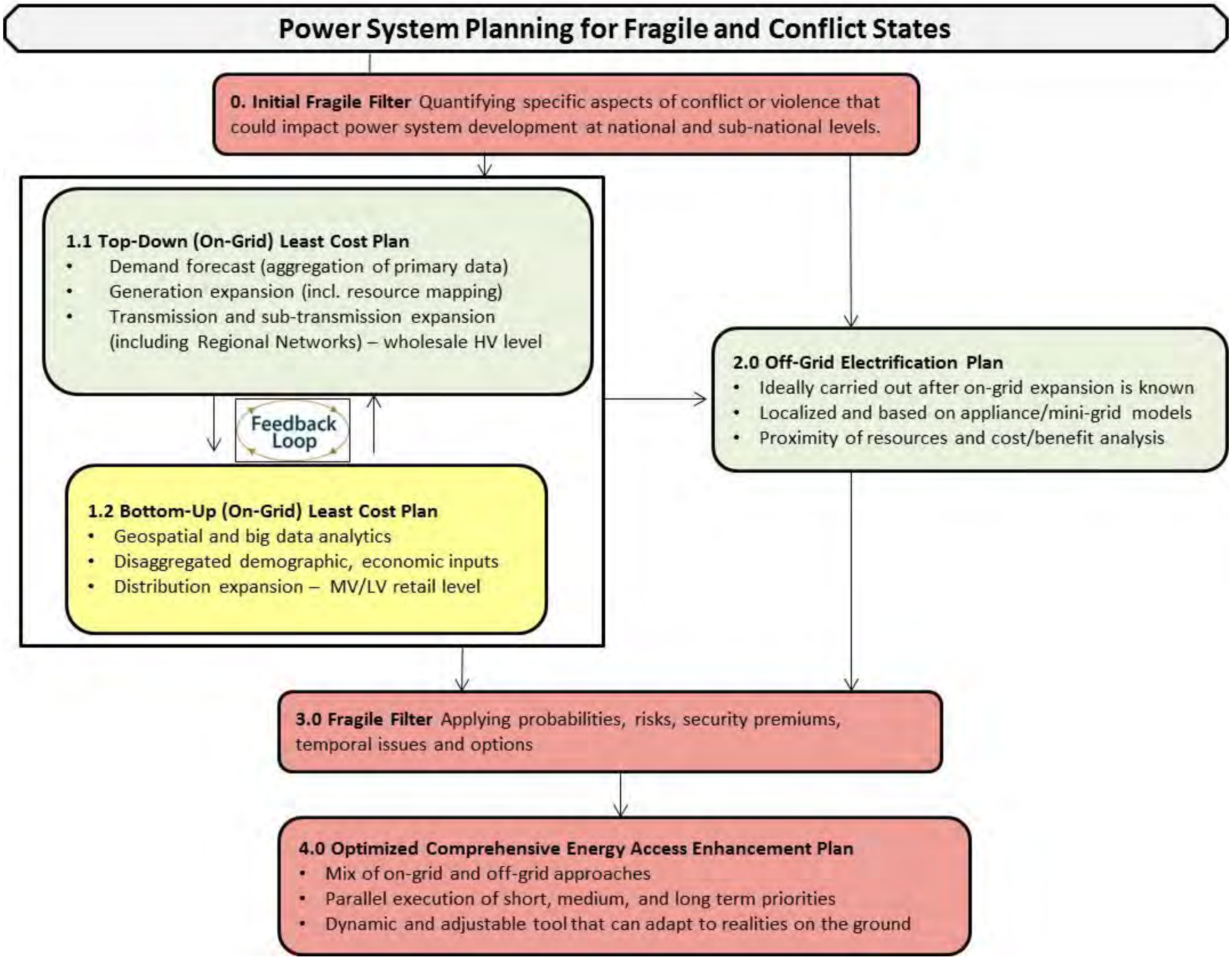

Figure 4: Schematic of a multi-stage planning process

In many of these fragile and conflict states, the capacity to undertake planning and the requisite institutional structures are simply absent. At the same time, there is no appetite from private sector investors to enter the countries. So short term-planning and medium term-planning might apply first the fragile filter, allow for the realities of conflict and severely constrained ability to put up large infrastructure, and begin incrementally with resilient and smaller systems. A realistic plan should explicitly take into consideration very high levels of risk and uncertainty, while acknowledging that large centralized systems are likely more easily targets for implementation failure or conflict targets. As alluded to previously, this is probably the central pillar of the case against centralized systems. In a sense, they are close to impossible for countries in deep conflict such as South Sudan. Risk factors are somehow proportional to scale. Something that on paper looks cost-effective is simply an invitation for rent-extraction from one group or another. The bigger the project, the greater the rent. Thus, one might argue that there is a whole dimension to the equation that is missing from normal least-cost analysis, not just an adjustment of inputs.

5. Case study: Republic of South Sudan

As the world's newest country, South Sudan is already trapped in a spiralling cycle of violence. Born as a petro state, the young country's short history has been dominated by oil-related concerns interwoven with ethnic and political issues. To understand the current situation in South Sudan is—to a large extent—to understand its relationship to energy.

The extremity of the circumstances in South Sudan is apparent through the numerous crisis appeals of relief organisations present in the country. In September 2014, the United Nations estimated that close to two million people have been displaced with little hope of returning to their homes in the near future, and up to one and a half million people are facing severe food insecurity with many on the brink of famine. This grave reality seems especially tragic in light of the initial great hope for the new nation, as its abundant oil wealth inspired prospects for a bright future. While the bulk of oil reserves in unified Sudan was located in its southern region, its population saw little, if any, of the large export revenues. Prior to the secession, these revenue streams helped to secure the Sudanese economy a decade-long growth averaging almost seven percent, which in turn sparked optimism for the creation of inclusive social and economic fundamentals under a new southern sovereignty.

As of late 2014, violence had spread to 7 out of 10 states in South Sudan and there is a real risk that Juba has lost control over the fighting completely. Just recently (as of August 24, 2015), peace talks, which to this point have been sporadic and unrewarding, were postponed yet again. There is an urgency for the vast international support arriving to the country to strike a balance between security, economic infrastructure and institution building. However currently, most eyes are on preventing what could become the worst famine in Africa for decades. The fighting, which has caused two-thirds of oil production to be shut down, has left the country in an austerity-like situation and deeply dependent on foreign aid.

a. Power Sector Planning Issues

South Sudan (as of June 2015) has less than 30 MW of installed diesel capacity serving pockets of loads in the towns, with no backbone transmission. It has electrification rate of under 10%—one of the lowest in the world. The country will eventually need to build an integrated power system to satisfy the large unmet demand, which can potentially grow by an order of magnitude (or more) over the next 2-3 years once political stability increases in the country. More importantly, long term power demand (by 2045) is expected to be another order of magnitude higher still; exceeding 2,500 MW. However, as the preceding discussion emphasizes, careful attention needs to be paid to the current political economy of South Sudan, and recognize significant risks associated with large-scale generation and transmission investments.

A recent report prepared by Hatch (2015) under the Nile Basin Initiative developed a long term capacity expansion plan that primarily focuses on developing a series of relatively large-scale hydro projects (especially Shukoli and Bedden) that would require $5.35 billion in new generation investment as shown in Table 4. The Hatch analysis is based on a standard least-cost capacity expansion planning methodology that does not consider the risks associated with raising capital in a fragile environment, potential significant delay and cancellation risks, and possible damages to the infrastructure during periods of insurgency.

Table 4: Proposed generation investment plan in Hatch (2015)

Plant	Capacity (MW)	Commissioning Year	Capital Cost ($m)
Palouge TPP	250	2,020	375
Tharjath HPP	240	2,020	360
Lakki HPP	300	2,033	658
Bedden HPP	522	2,028	1,295
Shukoli HPP	1,100	2,040	2,016
Juba HPP	120	2,050	365
Wau HPP	11	2,021	138
Fula HPP	39	2,021	143
TOTAL	**2,581**		**5,350**

Note: TPP is a thermal power plant. HPP a hydro plant.

The generation investment plan also foresees $910 million in new transmission infrastructure to evacuate power from the proposed generation projects. Figure 5 shows the proposed 220/400 kV lines most of which will cross areas where there have been severe incidents of violence in recent years. Any delay in construction of major transmission lines or damages to towers after they have constructed would also constitute a major challenge to meeting demand in future.

The conventional least-cost planning approach yields an investment plan that makes perfect technical and economic sense if these could be financed, developed in a timely manner, and operated in a conventional way. However, it is clear that there are significant challenges that need to be overcome on all three fronts. These challenges go beyond the realms of traditional planning. The central tenet that we have tested is whether incorporating the risks that underlie these challenges will mean a substantially different plan from the traditional plan. There are *prima facie* some good reasons to question the current plan, namely:

- Financing a $1-2 billion project (e.g., Bedden and Shukoli) in the current environment is highly unlikely. Although these projects are not planned for at least 13 years (25 years for Shukoli), counting on these even far into the future has some implications for more near term options.
- Any delay in even a single large project can have far reaching impact on the business environment and economic growth of the country. The 240 MW Thariath project planned in 2020 is a very large project in the context of South Sudan, and considering the long lead time of hydro projects, if it does not come online, scheduling connection for new townships, commercial and industrial loads will be severely impacted. If significant investment is tied in the project, it may also foreclose some of the other smaller scale options; and
- Even if the projects are successfully financed and developed on time, the operational risk stemming from either extensive damage to the power station or the transmission lines/substations

that are critical for evacuating power from these power stations, would almost certainly lead to a collapse of the entire grid, followed by extended periods of load shedding.

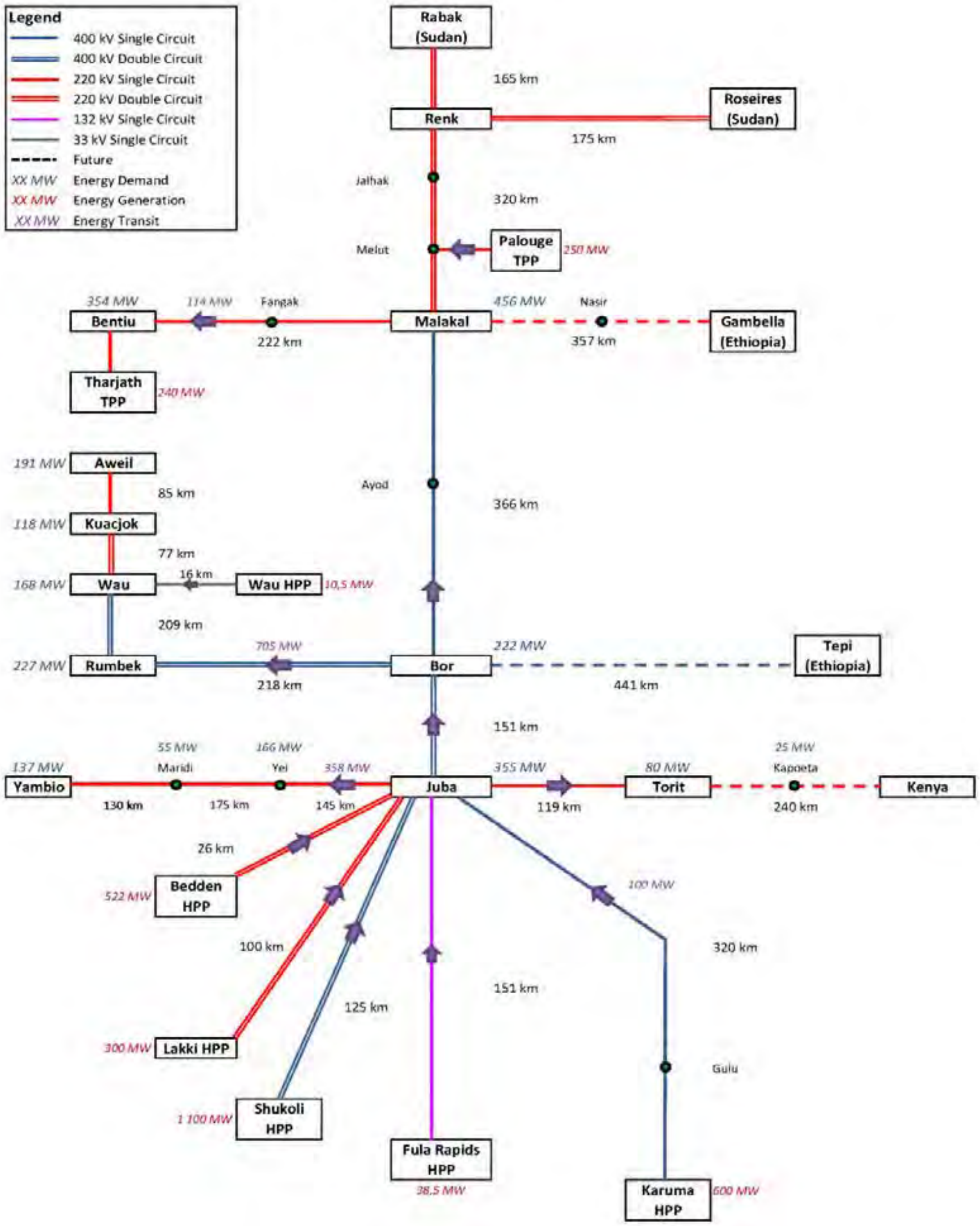

Figure 5: South Sudan transmission expansion plan

b. Planning in a Fragile Environment: Illustrative Examples

In this section, we illustrate how the conventional least-cost plan might change if we start bringing in some of the real-world constraints that investors, developers and plant/system operators face in a fragile environment. As we have discussed before, there is unfortunately no established methodology to capture these risks much less a uniformly agreed 'model'. Nevertheless, qualitative discussions on these issues or even limited quantitative analyses in the past have often tended to focus narrowly on one aspect of it, rather than consider the combined effect of all major issues. To be clear, this brief analysis considers differences in optimal generation expansion, it is not only focused on comparing grid and mini-grid (which is the emphasis of earlier sections).

For instance, a higher risk premium that captures all sorts of risks including 'sovereign risk' has been used as a proxy to capture a wide range of project/non-project/country risks associated with financing infrastructure projects by banks. Using a higher Weighted Average Cost of Capital (WACC) for inherently risky projects in conjunction with least-cost planning may be the simplest way to reflect risk in power systems planning. However, the translation of the type of catastrophic project risks that characterize a fragile environment has to be done carefully. World Bank (1995) study reflected that foreign IPPs investing in energy projects in developing countries typically required double the return (namely, 20-25% rather than 10-12% as noted in the report). This broadly aligns with more recent risk premium used by Moody, S&P and Fitch for CAA3 credit rated countries in the range of 10%-15%.

Figure 6 compares the LCOE of Shukoli and Bedden projects at a WACC of 10% and 20% with distributed solar (at $150 /MWh) and new diesel engine options ($242/MWh). Shukoli presents a better economies of scale at $1,832/kW compared to Bedden ($2,800/kW), and, even at a WACC of 20%, Shukoli is marginally cheaper than solar and remains significantly cheaper than new diesel. However, Bedden's LCOE at 20% exceeds $200/MWh making it significantly more expensive than solar, albeit it still remains 20% cheaper than the new diesel option. If WACC was increased to 25%, Bedden's LCOE would be $250/MWh making it more expensive than diesel and a 15% risk premium for South Sudan is quite plausible although we have not come across an estimate of this premium for energy projects in the country. Put differently, if we were to use a higher WACC as the only way to encapsulate all fragility risks: (a) the risk premium would typically be very high – perhaps double or more of a conventional WACC; and (b) the scale-efficiency of larger projects might still render the bigger and potentially financial riskier projects to be selected ahead of smaller and distributed options. WACC will not reflect the lumpiness of the project and hence the catastrophic risks associated with project delay/cancellation or operational contingencies (e.g., damages to the generating units, substation or towers during a conflict). A blanket increase in WACC for all large projects is, admittedly, a somewhat blunt tool.[11]

[11] Hydro typically very sensitive to assumptions about average utilization rates

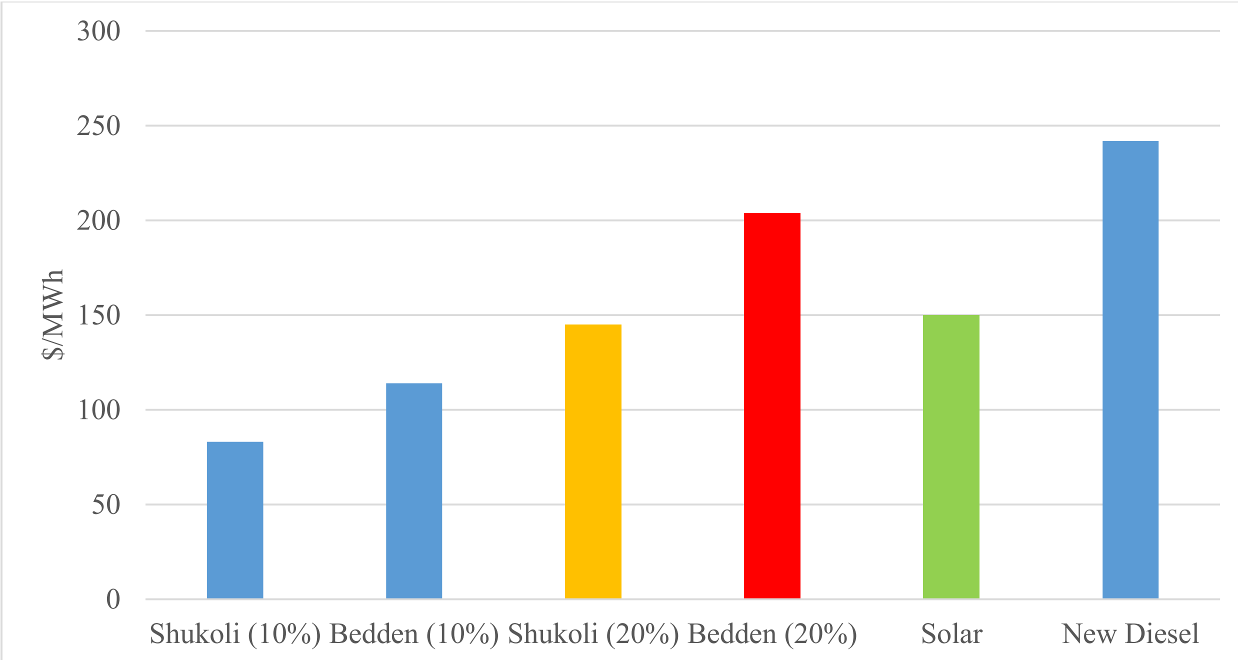

Figure 6: Comparison of LCOE ($/MWh) of hydro, solar and diesel projects in South Sudan

Note: The numbers in the parentheses for Shukoli and Bedden indicate the WACC used in calculating the LCOE

It is possible to assign progressively higher WACC to larger (and hence more capital intensive) projects to reflect significantly higher equity financing[12] that may be needed to support such a project (also the greater levels of rent-seeking and corruption that larger projects tend to attract, as well as likelihood of attack). Shukoli at 25% WACC will in this case will be $177/MWh and be more expensive than solar (at 10% WACC). Indeed, assigning WACC specific to the size of a project/investment in a structured way is not an easy task. One way might be to link the fact that outages (e.g. due to attacks) for large projects will presumably be longer (since re-build / repair time would tend to be longer for large projects). The risk and severity of default on loans is therefore higher during these longer outages. At the very least, this is an area that will require significant research and empirical evidence. Nevertheless, the discussion above highlights the simple fact that the ability to differentiate among WACC across projects can lead to a substantial swing away from larger projects to smaller/distributed counterparts.

A more elegant but also more data and analytically complex method is to recognize the financing costs for debt and equity and constraints that might be associated with both (e.g., a debt cap) *endogenously* in a least-cost planning model. Following the seminal work by Professor Stewart Myers at MIT in the seventies (e.g., Myers and Pogue, 1973) and eighties, these concepts have been discussed in the context of power system planning (Majumdar and Chattopadhyay; 1999, 2012). Majumdar and Chattopadhyay (1999) demonstrated how the work of Myers can be integrated into a standard least-cost planning model by explicitly introducing variables on debt and equity financing. This has been applied in the Australian

[12] It is recognized that the use of the term equity financing implies the involvement of the private sector in some manner. That is clearly not the case in States such as South Sudan at this stage.

context to explain how under policy uncertainty limited debt (and high cost of equity which effectively amounts to a significant rise in overall WACC), may explain an observed propensity to invest more in low capital peaking investment even though the conventional solution would be to invest in baseload (high capital) combined cycle plants. For the purpose of extending our analysis for South Sudan, we have assumed:

1. 60:40 debt/equity financing for all generation projects that would require $3.21 billion in debt to support a total of $5.35 billion in new investment over 2015-2045;
2. Return on equity of 25% reflecting high risk and a cost of debt of 7%; and
3. A debt ceiling of $2.4 billion, or 25% below unconstrained level. All other things being equal, the debt ceiling would increase the cost of capital intensive hydro projects relative to that of new diesel plants.

Finally, we bring in two other considerations, namely:

4. All hydro projects face a potential delay in start year. Figure 7 shows the project start time probability profile for Bedden. There is a 45% chance of a timely start, 45% chance of a delay by up to 3 years and a 10% chance of the project being cancelled; and

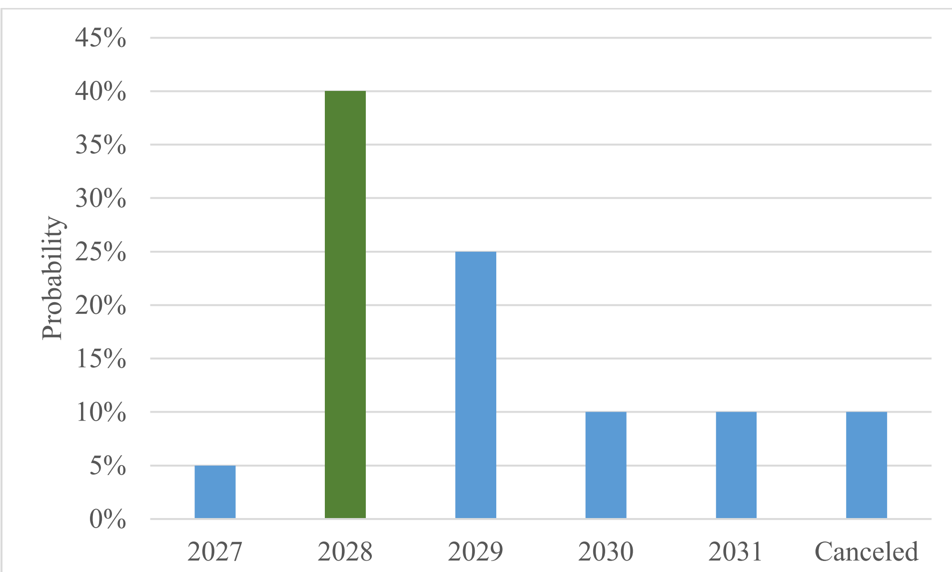

Figure 7: Bedden project start time uncertainty

5. There is also a 10% chance for all years of all big projects (>100 MW) and associated 220/400 kV lines to be damaged permanently.

We have developed a transmission constrained generation expansion model that minimizes total system costs subject to a set of technical and financial constraints. The optimization problem is formulated as a linear programming (LP) model. Total system costs include the capital and other fixed operational and maintenance (O&M) costs, fuel and variable O&M, and any cost of unserved energy. The constraints include physical demand-supply balance at each sub-station (i.e., generation and/or demand node), limits on flows for each high voltage transmission line, generation capacity limit, hydro energy limit and any limit on total capital available. The output of the planning model includes the least-cost mix of generation projects, dispatch decisions of all generating stations – existing and future, and flows on the lines. The model is populated using data from Hatch (2015) including the generation projects shown in Table 3 and the transmission network in Figure 8 to produce a conventional least-cost plan. We have then overlaid the fragility constraints (1)-(5) discussed above. Table 5 compares a conventional least-cost scenario that we have simulated using our LP model that ignores constraints (1)-(5), with a 'modified least-cost plan' that explicitly captures these. These constraints have a substantial impact on system costs raising it by $1.38 billion or 18% primarily because of the additional diesel generation cost of $1.07 billion that the latter entails. Part of the cost also is associated with additional cost of financing through equity, albeit on a lower capital base. Finally, there is higher unserved energy in the system as the limited capital availability limits the amount of 'firm' capacity that is needed.

Although the total capacity addition in the system for the two scenarios are quite comparable, the fragile scenario adds 443 MW additional (or, nearly double the solar capacity) compared to the least-cost scenario. Solar generation is variable and typically yields roughly an 18% utilization factor compared to 40%-50% of a hydro project. This explains the worsening of the reliability of the system with significantly higher expected unserved energy well above 1% of total energy requirement primarily due to solar variability. Generation investment is curtailed significantly in a fragile environment driven in part by the debt ceiling imposed and also in part due to a related increase in cost of (equity) financing. The most significant difference that it leads to is reflected in the mix of new capacity addition with capital intensive and uncertain hydro projects reducing from 1,922 MW in the least-cost to 339 MW comprising just two of the smallest projects (Lakki 300 MW and Fula Rapids 29 MW). Diesel capacity goes up significantly mostly in the town/city areas – nearly doubling the capacity result from the least-cost counterpart. (We note that diesel fuel supply chain has its own security implications that we have not modeled.) Solar, as we have just discussed, also goes up significantly.

Table 5: Comparison of traditional least-cost and modified least-cost plan with fragile filter

Parameter	**Traditional least-cost**	**Modified least-cost with fragile-filter**
Discounted system cost (2015-45) in $million*	7,592	8,971
Expected unserved energy (2015-2045) % of total energy	0.76%	1.23%
Generation investment ($b)	5.35	4.08
Hydro (MW)	1,922	339
New Diesel (MW)	1,198	2,354

Solar (MW)	531	974

Note: This includes annualized capital costs for all new generation projects, fuel costs, and costs of unserved energy (but does not include transmission investment costs).

Finally, Figure 8 and Figure 9 compare the capacity development profiles for the least-cost and modified least-cost scenarios. One of the key differences is that the former capacity plan is more 'lumpy' reflecting large hydro projects being added creating significant surpluses, followed by little capacity addition, whereas the fragile scenario is characterized by much more gradual capacity addition over the years. Solar and diesel complement each other with diesel providing the baseload (and some load following) role and solar helping to contain the amount of expensive fuel. As the mega hydro projects are not considered in the fragile scenario (Figure 9), the transmission extension to these projects are also not needed lowering the amount of capital from $910 million to $376 million. We have not explored the role that may be played by storage, or very small appliances like Solar Home Systems with battery. As such, the power grid in our illustrative case study continues to be a significant part of the supply with distributed solar and diesel generation augmenting the main grid.

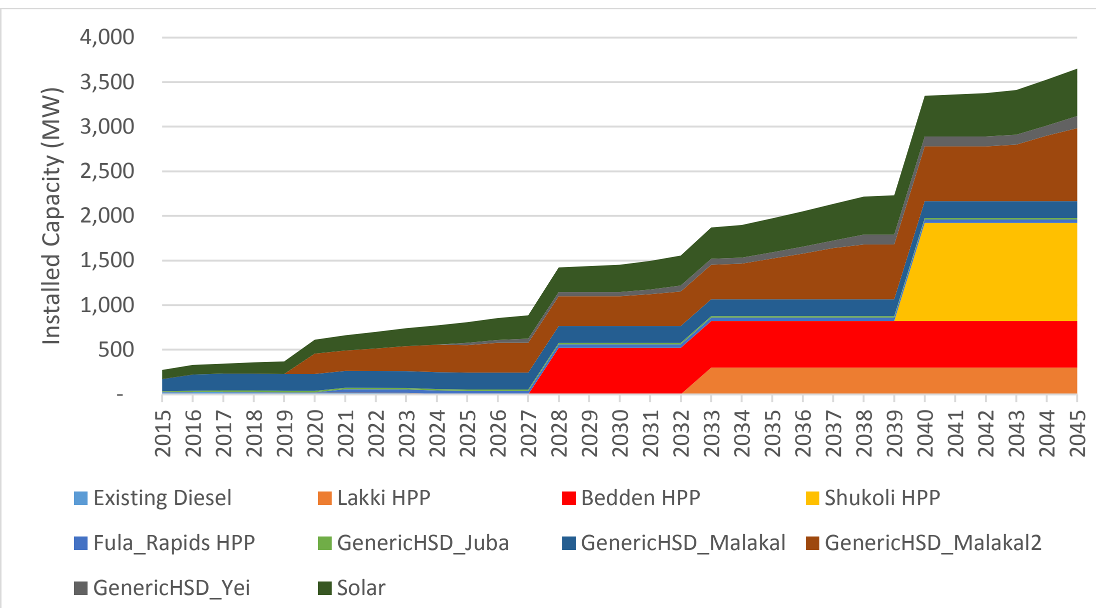

Figure 8: Least-cost capacity expansion plan

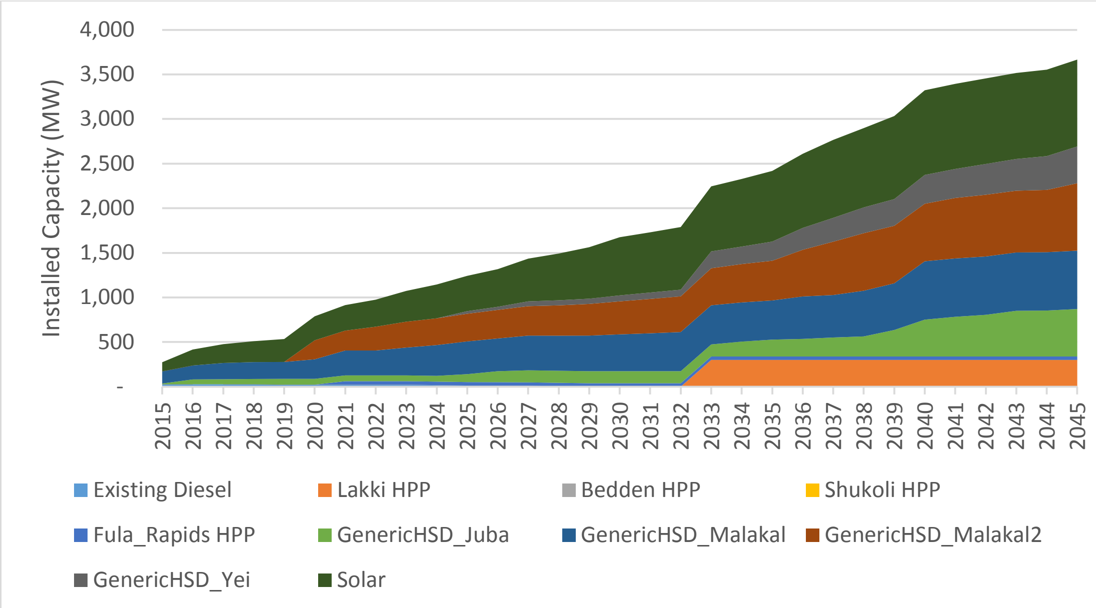

Figure 9: Capacity plan considering fragile environment

6. Discussion and Conclusion

We have presented a conceptual framework and an illustrative example of how traditional energy planning methodologies might be refined or augmented to find more suitable “answers” in fragile and conflict states. By assigning different risk weightings on various aspects of infrastructure development costs, we have shown that, in general, distributed (or smaller incremental) systems are likely more appropriate in such locations that suffer from instances of violence, or are unlikely to be able to secure large “chunky” finance at reasonable costs of capital. We employed only a limited amount of refinements on traditional methodologies, and did not go into other possible aspects of probabilistic or dynamic methodologies to address the core issues.

One issue with adjusting WACC, is how to provide some kind of objective basis for these adjustments. In the case study example, the adjustment is applied only to the large centralized solution, when presumably even decentralized solutions might be riskier in a fragile state than elsewhere. How can one convincingly determine the differential riskiness? Further sensitivities would be useful as well as, perhaps employing empirics from the risk premium literature. That said, these are likely to be heavily value-laden judgements in any case. Finding a more robust way to what an appropriate cost of capital would be is important and not obvious. One approach might be to identify an observable cost of capital in a country, and then correlate cost of capital with some of the fragility indices. Similarly, how do debt requirements vary with conditions related to fragility? Is there any analysis that can be done to benchmark this approach? Finally, the probability of damage approach is simple. But, why should we believe that the probability of damage is or will continue to be 10% (or any other fixed figure). Essentially, it is difficult if not impossible to specify a probability of damage. In these cases, other approaches are used such as:

- Solving for a critical damage probability that would make a project cost competitive or not and then comparing that damage probability to observed attack rates in other contexts.
- Identifying the vulnerability of different networked infrastructures and comparing the cost to the vulnerability.
- Developing a spanning set of scenarios and comparing the cost of projects across the spanning set to assess robustness

Another point that we did not explore was how does the fact that some technologies are more likely to be publicly or privately financed affect the risk story? It may be more likely that in situations where private sector investment is feasible (it is willing to participate) that this in itself help weight the risk sensitivities. In reality, none of these big projects will be privately financed, but even public institutions could usefully be thinking about financial risks in these ways. One way to think about it would be to try to come up with a fair valuation of a risk guarantee / insurance policy for the investment. Additionally, we did not cover in any depth the large literature on other ways to think of conflict or resilience outside of the energy sector. There is, of course, a wide range of organizations and researchers working in these areas that may well have more applicable concepts that might be usefully applied in the energy sector.

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