Journal of World Energy Law & Business

JWELB

Physics envy: why energy policy is more art than science

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Relying on restrictive definitions of energy security in an attempt to delineate security indicators is unnecessary to expedient policy analysis and may actually impede prudent decision making. Three cases studies are examined as evidence that a heuristic model of energy security that relies on experiential knowledge specific to the nation provides a more practical way to conceptualize energy security and results in more prudent security policy.

> I shall not attempt further to define the kinds of material I understand to be [obscene] . . . but I know it when I see it
>
> —US Supreme Court Justice Potter Stewart, 1964

1. Introduction

In the 1960s, the US Supreme Court struggled to define obscenity. Despite its collective brainpower, the Court found itself stymied. Watergate reporter Bob Woodward documented their herculean efforts, which included 'movie days' when the justices and their clerks viewed (with popcorn!) the pornographic films that were the subject of the many First Amendment cases awaiting the Court's decision.[1]

Despite such thorough review of the materials in question, the justices could not agree on which images were protected under the First Amendment and which were so obscene that they lacked constitutional protection. For Justice White, protected speech could not depict intercourse, sodomy of any kind or anything erect. Justice Brennan applied a simpler, bright-line test that his clerks jokingly referred to as 'The Limp Dick Test' (no erections). Justice Stewart used a different approach, what he called 'The Casablanca Test'. As a World War II Navy lieutenant stationed in Casablanca, Stewart had seen the locally produced hardcore pornography that his men brought back to the ship and knew how it differed from the pornographic material the Court watched on movie days. His difficulty articulating this difference, however, made his test an easy

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1 B Woodward and S Armstrong, *The Brethren: Inside the Supreme Court* (Simon & Schuster 1979) 239.

doi:10.1093/jwelb/jws032 Advance Access publication 11 January 2013

target of ridicule, especially by the snarkier clerks who would shout during the most lascivious scenes: 'That's it, that's it, I know it when I see it!'[2]

While not as scintillating a dilemma as faced by the US Supreme Court, contemporary energy policy analysts are facing a similar struggle: how to define energy security in ways that facilitate measurement and comparison between nations without removing energy security entirely from its social context. This struggle often has led to protracted debates in the academic literature (and even in person) about what indicators should or should not be included in any metrics designed to estimate or compare the effectiveness of national energy policies. Much of the energy security literature has tended to focus on security of fuel supply.[3] For energy security purists, securing the supply either of a specific fuel source or of the entire primary energy supply of a nation is the single most important indicator of national energy security; all other concerns are secondary.[4]

More recently, some energy security analysts have begun to focus on energy systems as a whole, not just the supply components. It is increasingly common, for example, to include the social, environmental and political aspects of energy systems in any analysis of a system's security.[5] For the purists, expanding the dimensions of energy security risks diluting analysis in ways that undermine its utility. Since an almost infinite number of factors can impact the security of a nation's energy system, it is nearly impossible to define energy security in ways that draw clear lines and direct useful evaluation.[6]

This article argues that trying to impose one simple definition of energy security that is useful in all comparative analyses is unnecessary to expedient policy analysis and may actually impede prudent decision making. Instead, it proposes more practical ways to conceptualize energy security than relying on restrictive definitions that pursue precision, but ultimately introduce inaccuracies. A heuristic approach to energy security is, instead, a tried and true method, rooted in sociology and tested through the effective and relatively mundane decisions that real people make every day.

Social psychologists have found that human beings (and even some machines) use experience-based techniques to reach quick solutions to complex problems. These heuristic strategies utilize readily accessible (though limited) information to develop 'rules of

2 Woodward and Armstrong (ibid).

3 DR Bohi and MA Toman, *The Economics of Energy Security* (Kluwer Academic Publishers 1996); A Cherp and J Jewell, *National Energy Security: Existing Metrics and a Proposed Framework*. Presentation before the International Workshop on Energy Security Concepts and Indicators for Asia, 29 October 2009.

4 In an attempt to 'reconcile security and the environment', eg the Institute for the Analysis of Global Security's, Luft and Korin simplify the complex relationship between the two as merely 'difficult trade-offs':

> If there is an inconvenient truth relating to our energy system, it is that while there are some overlapping solutions, we may not be able to address both issues in one strike, and too much emphasis on one could worsen the other. (15).

While somewhat obvious, this observation pays short shrift to the complexities that render 'too much emphasis' dependent on time, place and circumstance. See G Luft and A Korin, 'Energy Security: In the Eye of the Beholder' in G Luft and A Korin (eds), *Energy Security Challenges for the 21st Century: A Reference Handbook* (Praeger Security International 2009) 1–17.

5 MA Brown and M Dworkin, 'The Environmental Dimensions of Energy Security', in B Sovacool (ed), *The Routledge Handbook of Energy Security* (New York; CNA Military Advisory Board, 2007). *National Security and the Threat of Climate Change* <securityandclimate.cna.org>.

6 G Luft and others, 'Energy Security and Climate Change – a Tenuous Link', in B Sovacool (ed), *The Routledge Handbook of Energy Security* (Routledge 2011).

thumb' that generally lead to the desired outcome, if not the optimal solution.[7] When Justice Stewart articulated his rather amorphous definition of obscenity, he was really engaging in this process of cognitive heuristics. He relied on his experience with hardcore pornography in Casablanca to develop subjective criteria for defining obscenity that, arguably, were more useful—if not as easily articulated—than Justices White and Brennan's phallocentric definitions. Stewart could not define it, but his experience with pornography in Casablanca provided enough information that he knew obscenity when he saw it.

Similarly, when trying to identify energy security indicators, modern policy analysts should embrace the subjectivity inherent in their evaluations. Rather than subordinate the social, political and environmental dimensions of energy systems in an (ultimately unsuccessful) attempt to reduce energy security to precise boundaries that enable cross-jurisdictional comparisons, energy security analysts should adopt a heuristic approach that acknowledges that the human dimensions of security will often require adopting context-specific criteria. Ultimately, understanding that the factors that indicate energy security in one context may signal insecurity in another will produce more useful observations and more coherent policies.

2. Missing the forest: the bounded-awareness of reductive models

In a recent *New York Times* editorial, professors Kevin A Clarke and David M Primo opined that economists, political scientists and sociologists have long suffered from an academic inferiority complex they call 'physics envy'.[8] Physics envy entails the desire that social science be taken as seriously as the 'hard sciences' and is manifest by the widespread adoption of theoretical models that mimic the kind of narrow hypothesis testing found in laboratory research. While the authors acknowledge that physics envy dominates contemporary social science research, they warn that adopting the 'ideal hypothetico-deductivism' required in fields like physics and biology constrains the kinds of thinking about human behaviour that make the social sciences valuable to human decision making.

Clarke and Primo are not the first to observe the danger in applying the theoretical models of hard science to social research. German Chancellor Otto von Bismarck is famous (among other things) for declaring that, 'politics is the art of the possible'.[9] But it is his lesser-known quote that is often lost to the political scientists suffering from Clarke and Primo's 'physics envy': 'Politics is not a science . . . it is an art.'[10] In attempting to mirror science's methodological rigor (or to feign its objectivity), social scientists forget that human beings are a mess of contradictions and will consistently defy

7 G Gigerenzer and P Todd, *Simple Heuristics That Make Us Smart* (OUP 1999).

8 KA Clarke and DM Primo, 'Overcoming "Physics Envy"'. *New York Times*, 30 March 2012.

9 This is thought to be a remark Bismarck made to Meyer von Waldeck in 1867. However, there is no firsthand account of his exact words. See Ralph Keyes, *The Quote Verifier: Who Said What, Where and When* (St Martin's Griffin 2006).

10 See Otto von Bismarck, *Speech to the Prussian Upper House*, 18 December 1863. See <http://wist.info/bismark-otto-von/18704/>. accessed 24 December 2012.

attempts to rationalize their behaviour. Over a century ago, Russian novelist Fyodor Dostoevsky observed that humanity's 'unfettered desire'—its inherent humanness—'constantly smashed to smithereens' all grand systems and theories designed to describe and understand it.[11] Likewise, efforts by contemporary social scientists to define and measure energy security may help facilitate comparisons between nation-states. But to the extent those comparisons inform policy making, precision may impede prudence. Reductive models of energy security may be smashed to smithereens by social factors that are too context-driven to fall neatly into precise definitions.

Ironically, hard science is providing sound evidence for rejecting the application of its theoretical models to social science. Recent research has revealed, for example, that humans faced with a dizzying amount of information and tasked with making time-critical decisions often turn to experiential knowledge and cognitive biases to simplify complex decision-making tasks into a set of more manageable judgment calls.[12] Psychologists, for example, have observed how people tend to become overly focused on familiar data during the decision-making process and routinely overlook critical information right in front of them. While the keen focus on areas of expertise helps concentrate mental faculties, it also tends to limit awareness. Decision makers unintentionally ignore critical information that is readily available but outside their range of focus.[13] Thus, the boy scout helping an elderly person cross the road is crushed by the bus he never saw coming.[14]

Social scientists call this subconscious myopia 'bounded awareness' and have traced how it is responsible for disastrous (and sometimes fatal) decisions.[15] On the day of the Challenger space shuttle tragedy, for example, decision makers argued whether the chilly weather would affect the shuttle's O-rings. NASA scientists examined seven prior launches in which some sort of O-ring problem was observed, but found no pattern linking temperature to O-ring failure and allowed the launch to proceed. After that decision led to the deaths of seven crew members, NASA broadened the investigation and analysed data from all of the Challenger's 24 previous launches. The expanded data set revealed that the shuttle had more than a 99 per cent chance of malfunctioning on the day of its catastrophic launch.[16] When it mattered the most, their fixation on temperature caused NASA's scientists to overlook crucial indications that the O-rings were likely to fail not just from the weather, but from a combination of factors particular to the launch that day.

11 F Dostoevsky, *Notes from Underground* (Vintage 1994) 16.

12 ME Fendley, 'Human Cognitive Biases and Heuristics in Image Analysis' (PhD Dissertation, Wright State University 2009) <etd.ohiolink.edu/send-pdf.cgi/Fendley%20Mary.pdf?wright1257278185> accessed 12 December 2012.

13 Lee Merkhofer Consulting, 'Bounded Awareness & Decision-Making Heuristics', *Picking the Wrong Portfolio of Projects* (2007) <http://www.prioritysystem.com/reasons1c.html> accessed 24 December 2012.

14 Actually, they both are.

15 M Bazerman and D Chugh, 'Decisions without Blinders', *Harvard Business Review*, January 2006, 88–97.

16 M Bazerman and D Chugh, 'Bounded Awareness: What You Fail to See Can Hurt You', *Harvard Business School Working Paper #05-037*, Revised 25 August 2005 <www.people.hbs.edu/mbazerman/Papers/05-037.pdf> accessed 24 December 2012.

3. Trees that matter: applying a heuristic approach to specific cases

When energy security analysts insist upon reductive models they risk the same sort of bounded awareness that has been at the heart of disastrous policy decisions. Three case studies demonstrate how to approach energy security heuristically and why such an approach is more likely to produce more effective decisions about national energy policies.

Climate matters: the case of Browns Ferry

In August 2007, Alabama found itself in the grip of a record-breaking heat wave. For nearly two weeks temperatures soared past 100 degrees Fahrenheit. The temperatures fuelled brush fires across the state and created unbearable working conditions for fire-fighters trying to battle the blazes. Governor Bob Riley ordered junior college buildings and senior citizen centres opened 24 hours to give beleaguered citizens a respite from the heat.[17]

By early afternoon on 17 August, temperatures near the Tennessee border (where the Tennessee Valley Authority operates three reactors at the Browns Ferry Nuclear Plant) peaked at 104 degrees Fahrenheit. Water from the Tennessee River—used to cool the Browns Ferry reactors—reached 90 degrees Fahrenheit. Plant operators throttled back two of the plant's reactors to run at 75 per cent of capacity and were forced to shut down one reactor entirely.

'This all comes down to the drought and the hot water', a plant spokesman said at the time. But David Lochbaum, who had served as a nuclear engineer at Browns Ferry from 1980 to 1983, noted that the incident forewarned of a looming worldwide energy problem should policymakers turn to nuclear power as a carbon-free solution to global climate change. 'This is an unforeseen impact of global warming', Lochbaum told the Associated Press. 'These plants don't do very well in extremely hot weather.'[18]

Browns Ferry was hardly an anomaly. During a similar heat wave that struck Europe in 2003, nuclear plants across France were forced to shut down or override environmental regulations designed to protect fragile riparian ecosystems from the hot water discharged from reactor cooling towers. When the heat wave hit France, officials announced that 37 of the nation's 58 nuclear power plants would be allowed to discharge water into rivers at temperatures higher than regulations had previously allowed. According to a study by the National Surveillance Committee the high-temperature discharges led nitrogen to build up in the rivers and caused considerable damage to flora and fauna. Ironically, even given the allowances to discharge much hotter water than normally permitted, French utilities still had to import some 2,000 megawatts of electricity to compensate for power shortages in from the nuclear plants.[19]

France's situation repeated itself just three years later during the European heat wave of 2006. As temperatures across the continent soared yet again, European nuclear power

17 B Johnson, 'Record-breaking Heat Wave Maintains Grip on Alabama', *USA Today*, 15 August 2007.
18 J Reeves, 'How Weather Forces Partial Shutdown of TVA Nuclear Plant', *Associated Press*, 18 August 2007.
19 J Godoy, 'European Heat Wave Shows Limits of Nuclear Energy', *OneWorld.Net*, 28 July 2006.

plants found themselves more the victim of climate change than its solution. In Germany, plant managers throttled back reactors situated along the Elbe River. Still river temperatures continued to rise. So, managers at fossil-fuel power plants along the Rhine River had to cut back output as well.

The rest of Europe faired no better. In Spain, officials shut down the Garona nuclear plant as a precautionary measure after temperatures in the Ebro River exceeded authorized levels. And in the UK, National Grid issued an 'insufficient margin warning', prompting energy producers to resurrect mothballed conventional power plants to make up for potential electricity shortages.[20]

German energy guru Hermann Scheer declared that the situation demonstrated the urgent need for a radical change in European energy policy: 'We must massively invest in renewable energy sources, and get rid of nuclear power as soon as possible', Scheer told the German press.[21] David Lochbaum put it more clearly: 'we're going to have to solve the climate-change problem if we're going to have nuclear power, not the other way around.'[22]

Whether issues like climate change, typically characterized as 'environmental', should be included in any measure of energy security has become a point of considerable debate. Discussions of climate change among energy policy analysts have tended to bog down in arguments about mitigation strategies and emissions reductions. These debates inevitably involve sensitive issues related to rates of development and neocolonialism. Some energy analysts have reacted to these sensitivities by defining national energy security in ways that downplay the environmental and political aspects of energy systems.[23] Others, like former US Defense Secretaries John Deutsch and James Schlesinger, have noted that climate change mitigation must be considered an essential part of any attempt to secure energy.[24]

The incident at Browns Ferry in 2007 (and across Europe in 2006) demonstrates that the integration of climate change into energy security models transcends mere environmental concerns. Energy security models must consider climate not because national energy strategies could have a substantial effect on carbon emissions (though they most certainly can) but because radical changes in climate may significantly impact the security of planned or existing energy infrastructure, regardless of hoped for or achieved emissions reductions. As the Browns Ferry and European experiences demonstrate, nuclear power plants require vast quantities of fresh water to cool reactors. Water shortages or droughts resulting from warmer average air temperatures could reduce output or force plants to shut down just when electricity demand is highest.

Rising average global temperatures present a potential engineering pitfall for national energy strategies (like the strategy outlined by US President Barack Obama in 2010) that

20 ibid.

21 ibid.

22 'Nuclear Power Can't Take the Heat', 21 May 2007.

23 Cherp and Jewel (n 3).

24 MA Brown, 'The Environmental Dimensions of Energy Security', Presentation before the International Workshop on Energy Security Concepts and Indicators for Asia, Singapore, 29 October 2009; International Energy Agency, *Energy Security and Climate Policy – Assessing Interactions* (IEA 2007).

intend to rely on expanded nuclear power generation. Nuclear power plants generate electricity when steam passes through turbines at a high enough pressure to spin large fan blades. When the second steam enters the turbine chamber, however, it begins losing energy. Fortunately, condensation traditionally compensates for this rapid loss of energy. As nuclear-heated steam cools and water condenses, air pressure drops, creating a vacuum that helps pull the steam through the turbine blades. This condensation vacuum is essential to the electrical output of a turbine.

It is also incredibly vulnerable to global warming. As river temperatures rise as a result of increasing global average temperatures, it becomes far more difficult for steam to cool to the point of condensation. The force of the condensation vacuum diminishes and the plant has to expend more energy forcing steam through the turbines. Thus, as the ambient temperature of coolant water increases, electrical output from nuclear reactors and thermoelectric power plants decreases.[25] Climate change therefore represents a one-two punch to energy systems dependent on thermoelectric generation. As temperatures rise, electrical output decreases just as demand for energy to power air conditioning and other cooling systems skyrockets. To make matters worse, as an increasing number of transportation fleets transition to electric vehicles, demand will continue to increase. At some point, existing cooling systems will create serious limitations on the electrical output of nuclear power plants and other thermoelectric generating facilities. Energy policymakers that overlooked the effect of climate change on electrical output will be forced to make hard choices about how best to use dwindling water resources.[26]

Inequity matters: the case of the Mumbai slums

In 2009, a British film that had enjoyed only limited release in the United States shocked the entertainment world by winning eight Academy Awards, including Best Picture of 2008. *Slumdog Millionaire* tells the story of a young man from the Juhu slums of Mumbai who miraculously wins India's version of the hit game show 'Who Wants to be a Millionaire?' The film uncovered the plight of India's underclass in part by casting actual slum residents to play many of the critical roles.[27]

Hidden in *Slumdog*'s frenetic chase scenes are brief flashes of small, coloured ribbons hanging from the tangle of wires strung above the slum's corrugated tin and plastic tarp roofs. In a practice called 'hooking', elicit power cartels illegally tap the local electricity distribution system and charge slum dwellers for the stolen electricity. The coloured ribbons are used to indicate which wires serve which dwellings.[28]

At first glance the problem of illegal hooking appears to be a social equity issue, beyond the scope of any directed attempt to assess national energy security. But a purist approach to energy security in the world's second most populated nation could readily overlook that the greatest threat to India's energy security comes from within its own borders.

25 E Fleischauer, 'Heat Wave Shutdown at Browns Ferry Stirs Nuclear Debate', *Associated Press*, 7 September 2007.

26 B Sovacool and K Sovacool, 'Identifying Future Electricity Water Tradeoffs in the United States' (2009) 37 Energy Policy 2763–73.

27 'I Sometimes Feel Like I'm the Off-screen "millionaure": Loveleen', *Hindustan Times*, 1 January 2009.

28 B Richardson, 'India's Power Dilemma', *BBC News*, 16 July 2009 <http://news.bbc.co.uk/2/hi/business/8149710.stm> accessed 24 December 2012.

India's electricity supply industry is mainly owned and operated by the public sector. Price levels and subsidies are set by politicians with vested interests in keeping prices low and subsidies high. Because of liberal subsidies, however, in many cases electricity prices charged by the cartels exceed the official market rate. This begs the question: why would slum dwellers choose to pay more for stolen electricity rather than seek cheaper (and legal) electrical services from the state?

In addition to several sociological and infrastructural barriers, some investigators have identified economic barriers to traditional electrical service that may be overlooked by energy security models that ignore the realities of life in India's slums. For example, most slum dwellers rely on informal and irregular work. This means that regardless of the size of their income, it is often occasional and cannot be depended upon like a salary. As a result, even the most affluent slum dwellers cannot budget for regular electrical service. Instead, they find themselves able to pay a higher per unit price for electricity when their cash flow allows.[29]

Slum families often are squatters with no legal status. Thus, there is no official connection between slum dwellers and where they reside. Consequently, utility companies find it extremely difficult to bill slum-located consumers successfully. Without mail service in the slums, companies would be obliged to establish their own collection services (probably at great expense).[30]

Regardless of the motivations, the combination of illegal hooking and profligate state subsidies means that the revenues India's utilities have collected have not kept pace with the costs they have incurred developing and operating India's electrical system. The entire industry is running a growing risk of total bankruptcy. With little to no investment in improved or expanded infrastructure, the increasing gap between supply and demand has resulted in a sharp decrease in the ratio of electricity consumption growth to growth in gross domestic product (GDP).[31] India's economic development is hampered by the fact that each unit of economic growth requires more energy than many of its competitors. The result is that, relative to nations that have decreased their energy intensity, India has even less public funding available for necessary system maintenance, upgrades and expansion.

Of even greater concern, illegal hooking has a direct impact on India's energy security by degrading the quality of electrical services, increasing the risk of catastrophic voltage collapse and threatening the reliability of the entire transmission network. By 1998, official (and probably underestimated) transmission and distribution line losses in India reached 25 per cent, with much of the loss attributed to so-called 'non-technical losses'—actually unpaid or stolen electricity.[32] Line losses represent more than lost revenue,

[29] D Schaengold, *Clean Distributed Generation for Slum Electrification: The Case of Mumbai* (Woodrow Wilson School Task Force on Energy for Sustainable Development, 8 May 2006) 6.

[30] International Energy Agency, Electricity in India: Providing Power for the Millions (OECD/IEA 2002).

[31] ibid., 13.

[32] ibid.

however. There are several characteristics of power transmitted through high voltage lines that are affected in different (and sometimes dangerous) ways by non-technical line losses. For example, many types of customer equipment require line voltage to fall within a narrow range in order to function properly. If delivered voltage is too low, electric lights dim and electric motors function poorly and can overheat. Overly high voltages shorten the lives of lamps substantially and increase motor power, which can disrupt manufacturing systems and damage attached equipment.

To understand the ultimate threat to energy security India faces from within, one must understand the relationship between frequency and voltage in modern electrical transmission systems. Unlike frequency, which is the same at all locations in the power system, voltage varies from point to point in an electrical grid. The voltages throughout a power system depend on the voltage output of individual generators and voltage control devices, as well as the flow of the electrical charge through the system.

To allow electrical devices to work properly, system operators must maintain voltage within a narrow range by balancing the supply and demand of reactive power in the system. If we think of raw power (current) as the actual electrons in the system, reactive power is the energy needed to keep those electrons flowing. It generally is delivered as a product of greater real power output from central generation stations or is provided by expensive dynamic capacitors installed at various points along the transmission line. Electrical engineers measure reactive power in VARS (for 'volt amperes reactive').

Understanding the difference between raw and reactive power helps explain why India's internal threats to electricity transmission may present more dangers than any external threats to fuel supply. Because power lost through transmission is not equally distributed, stolen electricity creates a potentially devastating problem. One way to conceptualize the difference between real power (current) and reactive power (voltage) is to think of an electrical transmission and distribution system much like modern plumbing. Think of current as the actual water flowing through the complex network of pipes and voltage as the water pressure in any given pipe. Now imagine that someone made a small puncture somewhere in the piping system. In the grand scheme of a municipality's water system, the raw 'amount' of water seeping through this small hole may not represent an important loss. But the water 'pressure' lost as a result of even a small puncture is orders of magnitude greater and can substantially undermine the ability of the system to deliver water to customers. Without adequate pressure, water cannot reach customers further away from the central source, no matter how much actual water there is.

Similarly, when transmission lines are tasked close to their capacities, reactive power (voltage) losses are significantly greater than real power (current) losses. In addition, engineers have calculated that reactive power losses increase exponentially with the distance the electricity is transmitted. Just as more water is required to maintain the same water pressure the further away the water must be pumped, more reactive power is necessary to deliver raw power when there is greater distance between where power is generated and where it is used. As the distance between the generating unit and the customer increases, the reactive power required to maintain stable voltages increases.

The difference between real power and reactive power line losses is important when considering illegal 'hooking', especially in nations that are experiencing substantial development gaps between classes. As poorer families scramble to meet their power needs by hook or by crook (or, in India's case, both), the resulting line losses represent a very real threat to the security of the nation's electrical grid. Indeed, in modern electrical power systems, catastrophic failures are rarely the result of inadequate supplies of real power.[33] More often, systemic outages are triggered by voltage instability resulting from insufficient reactive power.

A significant causal factor in major power outages worldwide from 1978 to 2003 was inadequate reactive power leading to systemic voltage collapse.[34] Voltage collapse was responsible for blackouts on the west coast of the USA on 2 July 1996 and 10 August 1996. Voltage collapse also factored into major blackouts in Paris (1978), Tokyo (1987), Quebec (1989) and London (2003), and in Sweden, Denmark and Italy during the 2003 European heat wave.

But the Eastern North American blackout of 2003 provides arguably the best example of how voltage instability can bring down an entire electrical grid. Around 1:30 pm one sunny afternoon in August, a generating plant in Eastlake, Ohio unexpectedly shut down. By 2:02 pm, the loss of real and reactive power supplied by the Eastlake plant required system operators to direct greater current over transmission lines that could access other generation. But the additional raw current caused the first of several 345 kilovolt lines in northeast Ohio to became overloaded, heat up and start to sag. Eventually the sagging line came into contact with an overgrown tree. As a security measure, system operators shut down the sagging lines, causing a progressive loss of current in some areas and current spikes in others. By 3:17 pm, the rapidly changing currents caused voltage to dip precipitously on the Ohio portion of the northeast grid.

Because reactive power losses are greater than real power losses, the relatively minor loss in raw power caused relatively large voltage drops throughout northern Ohio. Ohio system operators compensated by drawing power from generating units in Michigan. Tapping this remote generation source, however, created wild voltage oscillations and caused several more transmission lines to trip offline to protect themselves. In response to the unstable voltages, power plants in Ontario began to take themselves offline. Seconds later, in an attempt to protect critical system components from damage the Ontario power grid separated from the western New York grid. In an attempt to save itself, northern New Jersey separated its power grid from New York and the Philadelphia area, causing a cascade of failing secondary generation plants along the Jersey coast. Seconds later, a large area from Lansing, Michigan to the eastern seaboard, including New York, Ontario and a large portion of Ottawa was left without power as more than 508 generating units at 265 power plants shut down automatically. What resulted was the

33 In India, even as energy intensity has increased, the government has substantially increased electrical capacity since 1998. Power generation has also increased rapidly from 301 terawatt hours in 1992 to 451 terawatt hours in 1999—an average annual growth rate of just over 6 per cent. See IEA (2001), supra note 30, 33.

34 Federal Energy Regulatory Commission, *Principles for Efficient, Reliable Reactive Power Supply and Consumption*, Staff Report, Docket No. AD05-1-000, 4 February 2005.

second most widespread electrical blackout in history, affecting an estimated 10 million people in Ontario and 45 million people in eight US states.[35]

The joint Canadian–US task force assigned to investigate the 2003 East Coast blackout found that, much like the other major blackouts of the late 20th century, the cause of the outage was not that the system had insufficient raw power to meet the demand for electricity.[36] Instead, investigators concluded that the unfortunate series of events that led to the second largest power outage in history was precipitated by insufficient reactive power available during the initial events that led to the blackout.[37]

Investigations of voltage collapse in the USA have revealed that remote generation of reactive power is inherently unstable.[38] The farther generation is located from the where it is used, the more current is necessary to make up for the lost reactive power. But greater current also risks larger voltage drops along the path. As voltage drops, current must increase to maintain the power supplied, causing lines to consume more reactive power and the voltage to drop further. As the 2003 east coast blackout demonstrated, if voltage drops too low, some generators will automatically disconnect to protect themselves. This further loss in generation causes further reduction in remotely supplied reactive power, necessitating greater line charging to make up the difference and risking a positive feedback loop. As lines are charged to make up for the lack of reactive power, current spikes and causes more generators to trip offline, necessitating more current to make up for even greater losses in reactive power. The result is a progressive and uncontrollable system collapse much like what was witnessed in North America in 2003.

Given what electrical system engineers know about modern electricity transmission systems and experience with catastrophic system collapses over the past 30 years, energy policy analysts should consider voltage instability as great a threat to national energy security as a nation's inability to meet growing electricity demand. In the context of modern electrical transmission systems, illegal 'hooking', for example, becomes much more than a socioeconomic issue. It becomes a significant factor in the security or insecurity of any national energy system that relies on generating electricity from large, centralized generating units. Because reactive power losses due to illegal hooking are not commensurate with real power losses, each instance of hooking represents a voltage perturbation requiring larger amounts of raw power supplied from remote sources. But the short-term system stability derived by supplying reactive power from distant sources is gained at the expense of longer-term systemic voltage stability, which, as the 2003 East Coast incident demonstrated, can be the difference between a minor line fault in Eastern Ohio and plunging 55 million people into total darkness.

The case of illegal 'hooking' in the Mumbai slums demonstrates the danger of conventional approaches to energy security. Turning to reductive models of energy security,

35 U.S.-Canada Power System Outage Task Force, 'Chapter 5: How and Why the Blackout Began in Ohio', *Final Report on the August 14, 2003 Blackout in the United States and Canada: Causes and Recommendations*, North American Electric Reliability Council, 5 April 2004.

36 Indeed, the Harding–Chamberlain 345 kilovolt line that initiated a domino-effect of line outages in northern Ohio was operating at only 45 per cent of its allowable limit at the time it tripped.

37 See n 34.

38 ibid.

some energy policy analysts may focus too much on external threats to energy supply while overlooking much greater internal threats to energy quality. This kind of bounded awareness risks large-scale catastrophes like the 2003 North American blackout. A heuristic approach, however, driven by the context of India's specific energy system, is more comfortable with expansive definitions of energy security and, hence, more likely to recognize how unconventional factors may represent serious threats to national energy security.

Demand-side matters: the case of Tonle Sap

Tonle Sap (literally 'Great Lake') is the largest freshwater body in Southeast Asia. Every June, rain falls so heavily in eastern Cambodia and rushes downstream in such volumes that the Tonle Sap River actually reverses its flow. Water is pushed up the river by seasonal monsoons turning an inland lake normally the size of Rhode Island (and rarely more than a meter deep) into an inland ocean stretching nearly 16,000 square kilometres and reaching depths of up to nine metres. Fish from the lake support over 3 million people and provide over 60 per cent of the Cambodian people's annual protein intake.[39]

Tonle Sap is home to many ethnic communities living in floating villages around the lake. While some traditional Khmer houses on stilts dot the periphery of the lake, most of the houses in these communities float, rising and falling with the ebb and flow of the water level. Homes range from elaborate rafts and barges to simple, covered fishing boats to mere flotsam and jetsam lashed together in makeshift flotillas. Like other communities, the floating villages of Tonle Sap have schools, restaurants, temples and even hospitals, all built on boats.

As the sun sets over the lake, the air becomes thick with swarms of mosquitoes; the night sky is reflected across the black expanse, interrupted only by hundreds of bright, flickering squares bouncing along the water—the glow of big screen televisions. The residents of Tonle Sap's floating villages may not have modern toilets, running water or access to networked power (in rural areas like Tonle Sap, official statistics estimate that almost 85 per cent of residents lack access to networked electricity service), but many do have televisions powered by diesel-fuelled generators or used car batteries. This widespread use of distributed generation is evidence of the Cambodian people's resilience and creative perseverance despite years of war and internal conflict that has crippled much of the country's electricity infrastructure.[40]

Accurate data on Cambodia's energy supply and consumption is hard to come by. But the Renewable Energy & Energy Efficiency Partnership estimates that the country's public and private grid systems have around 516 megawatts of total installed capacity, of which about 65 per cent is located near and serves the capital city of Phnom Penh. However, this figure does not include a large number of commercially owned standby generators, nor

[39] See Wikipedia, Tonle Sap <http://en.wikipedia.org/wiki/Tonlé_Sap> accessed 12 August 2010.

[40] B Tonnkunthel, 'Cambodia's Profile in Power Sector', Presentation at the First Mekong Energy & Ecology Training, 11–30 May 2009, Thailand, Slide 2 <http://www.probeinternational.org/files/powerpoints/Cambodia%20Profile%20in%20Power%20Sector.ppt> accessed 9 August 2010).

does it count the hundreds (perhaps thousands) of small diesel generators used in places like Tonle Sap by private entrepreneurs supplying rural residents with battery charging services.[41]

Electrical capacity in Cambodia is currently fragmented into 24 isolated power systems fuelled entirely by diesel generators (except for two small hydropower stations). This reliance on a large number of old, small generators and the complete importation of diesel fuel means electricity prices in Cambodia are the highest in the region (and among the highest in the world). According to 2000 data from the Royal Government, while residents in Phnom Penh pay an average tariff of US$0.15 per kilowatt hour, residents in rural areas can pay upwards of US$0.50 per kilowatt hour.[42] In some districts outside Battambang, residents have reported paying US$0.75 to $1.25 per kilowatt hour.[43]

Experts forecast dramatic continued growth in Cambodian real GDP, averaging 6.1 per cent a year through 2014. With this growth comes soaring demand, from an estimated 1.7 terawatt hours in 2009 to 3.0 terawatt hours by 2014, a 69 per cent increase in electricity consumption. But analysts warn of possible electricity shortages should the country's power industry not find new capacity to meet this increasing demand.[44]

In an attempt to address energy security concerns, the Royal Government is pursuing an aggressive expansion of domestic generating capacity, including exploration of off-shore gas and oil reserves. Anticipating massive deposits of natural gas in the Gulf of Thailand, the Cambodia National Petroleum Authority (CNPA) is coordinating development of a vast gas pipeline system and preparing large, energy intensive industrial projects.[45]

Conventional models of energy security could easily describe Cambodia's efforts to expand domestic electricity generation, diversify its fuel sources and pursue offshore deposits of oil and natural gas as indication of an aggressive energy security strategy designed and a responsible reaction to anticipated risks to the nation's energy supply. However, a more heuristic approach might look to energy security factors specific to Cambodia's government and foreign relations. Such an approach is less likely to overlook important contextual clues indicating that the Royal Government's strategy actually creates more broad-based security risks than it solves.

The largest block of Gulf territory being explored by the Royal Government is known as the Overlapping Claims Area (OCA) and is claimed by Thailand as well. Widespread speculation in the early 2000s that the area could contain huge oil deposits led to heightened tensions between the two countries, prompting a memorandum of

41 Renewable Energy & Energy Efficiency Partnership (2011). Cambodia Profile, REEEP Policy Database. <http://www.reegle.info/policy-and-regulatory-overviews/KH> accessed 24 December 2012.

42 ibid. Tonnkunthel (n 40).

43 Tonnkunthel (n 40). Ibid.

44 'Cambodia Power Report Q3 2010', *Business Monitor International*, July 2010 <http://www.mindbranch.com/Cambodia-Power-Q3-R302-11539/> accessed 9 August 2010.

45 HE Te Duong Tara, 'Oil Supply Security Concerns in Cambodia: Status of Current Exploration and Production and Future Plans for Oil & Gas Production', Presentation before the IEA/ASEAN/ASCOPE Workshop on Oil Supply Disruption Management Issues, 5–8 April 2004, Siem Reap, Cambodia.

understanding in 2001 that was intended to lay the groundwork for joint development of the disputed territory.[46]

But since then, territorial disputes have substantially deteriorated diplomatic relations between the two countries. In 2003, Cambodians burned down the Thai Embassy in Phnom Penh after a newspaper falsely alleged that a famous Thai actress claimed that the ancient temples at Angkor Wat belonged to Thailand.[47] Since 2008, the countries also have engaged in a series of deadly skirmishes involving the long-running dispute over which country has rights to the border territory surrounding the 11th-century PreahVihear Temple.[48] Thai politicians representing the People's Alliance for Democracy have made the issue a cause célèbre after Cambodia, without first consulting Thailand, applied to have the area designated a World Heritage Site by the United Nations.[49] The conflict intensified through 2011, leading to several fatalities, hundreds of civilian and military injuries, the burning of several villages and disruption of cross-border economic activities.[50]

The land disputes have complicated diplomatic attempts to resolve the overlapping maritime claims in the Gulf of Thailand. A 2006 military coup against the elected government of Premier Thaksin Shinawatra also has seriously complicated joint development efforts in the gulf. In 2008, the Cambodian Navy stepped up patrols in the vicinity around the disputed oil fields.[51] And late in 2009, Thai Foreign Minister Kasit Piromya announced that his country had decided to cancel the 2001 joint development agreement after Cambodia's Royal Government named the exiled Shinawatra as a senior economic advisor to Cambodia. The military-backed government saw the political move as such an affront that Piromya's deputy even hinted that Thailand would shut off all border checkpoints should Cambodia not compromise on Thaksin's appointment.[52]

In December 2011, both parties agreed to a cease fire and to begin negotiations over disputed territories. The government of Thailand proposed to separate the OCA vertically, suggesting that Thailand retain 80 per cent of the revenues derived from the western side, while Cambodia retain 80 per cent from the eastern side. But the Cambodian government objected since there was much speculation that the western part of the OCA contains more gas deposits than the eastern part. Instead, the Cambodian government proposed a 50/50 revenue split. That proposal was rejected and, by May 2012, the countries had yet to reach an agreement on how to share OCA revenue.[53]

46 'Next Stop for Big Oil: Cambodia?' *Business Week*, 15 February 2008.

47 'Sondhi Plays PAD Mediator', *Bangkok Post*, 30 March 2006 <http://www.asiamedia.ucla.edu/article.asp?parentid=41780> accessed 12 August 2010.

48 Jonathan Head (2008). 'Political tensions driving temple row,' *BBC News*, 15 July. Available at: <http://news.bbc.co.uk/2/hi/asiapacific/7507425.stm> accessed 12 August 2010.

49 ibid.

50 Morentalisa, 'Thailand-Cambodian Border Dispute: It's All About the Oil', Merekam Gagasan, 18 January 2012 <http://morentalisa.wordpress.com/2012/01/18/thailand-cambodia-border-dispute-its-all-about-the-oil/> accessed 24 December 2012.

51 See n 46 above.

52 Thaksin was ousted in a military coup in 2006 and fled the country amid charges of corruption. A Konglang, 'Thais Scrap Cambodia Oil Deal in Thaksin Row', *Agence France Presse*, 5 November 2009.

53 See n 49 above.

Should Cambodia successfully navigate the diplomatic minefield of its overlapping maritime claims and begin to extract significant energy reserves from the Gulf of Thailand, it by no means ensures a greater level of security (energy or otherwise) for Cambodia's people. State ownership has bred so much corruption among the gas-and-oil rich countries of Southeast Asia that economists have coined the phenomenon, 'the oil curse'.[54] Global Witness, a UK-based non-profit organization best known for helping expose the West African trade in 'blood diamonds', has warned that Cambodia's coming oil wealth may simply entrench the country's ruling cabal, already rated the 18th most corrupt in the world by publishers of the globe's leading corruption measure.[55]

Indeed, the Cambodian fuel rush has led many foreign firms to cut deals with Cambodia's ruling party, which has carved the nation into 20 odd oil-and-gas districts awaiting development as soon as the territorial disputes die down.[56] The details of the contracts are kept secret by Cambodia's deputy prime minister and the head of CNPA.[57] But according to Human Rights Watch, Cambodia's military already has forcibly removed hundreds of families from areas under concession, torching their homes to make way for excavation by international oil and gas firms.[58]

The oil rush has also prompted the Cambodian government to explore deposits in the Tonle Sap as part of a long-term energy strategy it claims will develop the country and reduce poverty. In 2010, the Cambodian government granted Japan's state-affiliated Japan Oil, Gas and Minerals National Corporation rights to survey for oil in a 6,500 square kilometre area of Tonle Sap.[59] Under the agreement, the countries will cooperatively evaluate business opportunities, potential drilling sites and private sector development opportunities.

Claims that private sector hydrocarbon development will translate to less local poverty should be met with scepticism. Multinational oil and gas firms have a chequered record improving the local economies where they operate. International companies like Shell Petroleum, Mobil and Chevron have been operating in the poverty-stricken, rural areas of the Niger Delta since 1972. But, despite promises by the companies, communities along the Delta remain impoverished. Roads have yet to be paved, water has been contaminated, subsistence farmers find their livelihoods destroyed by frequent oil spills (practically one oil spill every day for the past 25 years) and human health has deteriorated.[60] Even when modern oil and gas infrastructure prevents leakage, the construction of huge drilling projects itself causes pollution and alters the water systems that residents have relied on for centuries. So too does the flaring of gas at well sites. In the Niger Delta, where companies have constructed over 100 flare sites, residents complain that they can

54 See n 46 above.

55 'Cambodia's Coming Oil Wealth Will Likely Entrench Ruling Cabal in Corruption', *Huffington Post*, 18 March 2009 <http://www.huffingtonpost.com/2009/03/18/cambodias-coming-oil-weal_n_176384.html> accessed on 12 August 2010.

56 ibid.

57 See n 46 above.

58 See n 54 above.

59 Energy-Pedia, 'Cambodia: JOGMEC to Survey Cambodia's Tonle Sap Basin', 4 May 2010 <http://www.energy-pedia.com/article.aspx?articleid=140167> accessed 24 December 2012.

60 B Abah, 'When Blessing Becomes a Curse in the Niger Delta [-Will this be the Tonle Sap's fate?]', *KI-Media*, 6 May 2010 <http://ki-media.blogspot.com/2010/05/when-blessing-becomes-curse-in-niger_06.html> accessed 24 December 2012

no longer collect rainwater for drinking since it is contaminated with soot from the gas flares.[61]

Discontent over reduced standards of living and frustration over government corruption has sparked a series of uprisings in the Niger Delta that have claimed the lives of over 1,000 people annually. In one notorious incident, military operatives paid by Shell allegedly moved into some Delta communities with tanks and guns, shooting and killing hundreds of people after four chiefs sympathetic to the oil companies were murdered by an irate mob of village youths.[62]

It is difficult to claim that such conditions, reproduced in Cambodia's rural communities, would represent a measurable (and desirable) increase in national energy security. Yet conventional models of energy security rationalize Cambodia's efforts to diversify its fuel supply and expand access to centralized electrification. Indeed, almost all reductive theoretical models identify these efforts as critical indicators of energy security.[63] In many cases, these models provide justifications for governments to intervene in energy markets even when (as with the case of Cambodia) such interventions risk the welfare of a large segment of the nation.

4. Conclusion

Just as the pursuit of scientific precision sometimes can obscure the forest by focusing on the trees, conventional energy security models risk simplifying the relationship between security of primary fuel supply and context-specific factors that are better indicators of energy security. As these three case studies demonstrate, reductive models tend to ignore the complexities that make some factors more or less critical depending on the specific time, place and circumstances under which decision makers consider national energy policies. A heuristic approach to energy security is at once more narrow and more expansive. At the same time that it embraces a broader definition of energy security, it also applies different definitions given the specific context in which energy policies are considered. By incorporating these complexities, a heuristic approach may operate more like Justice Stewart's awkwardly imprecise definition of obscenity. While its contours are obscure and its application subjective, it is arguably more useful by avoiding bounded awareness, uncovering more valuable data and directing more prudent policy making.

A more heuristic approach to energy security is likely to be met with much scepticism from social scientists who understandably eschew the awkwardness and imprecision of such a model. Nevertheless, even while heuristic approaches to energy security require more rigorous testing in real-world circumstances, clearly energy policy makers would benefit from a better understanding of the complex interactions between security and the environment, between socioeconomic inequality and voltage stability, and between primary national fuel supply and internal politics.

61 ibid.

62 ibid.

63 AC Badea, 'Energy Security Indicators', Presentation before the European Commission Joint Research Center, Institute for Energy, Belgrade, 19–21 May 2010.