Arizona's Solar Market Analysis and Research Tool

Impact of Solar Generation upon Arizona's Energy (Electricity) Security

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Arizona's Solar Market Analysis and Research Tool (Az SMART)

Arizona's Solar Market Analysis and Research Tool (Az SMART) is a breakthrough analysis environment that will enable stakeholders to examine the complex interaction of economic, security, environmental, and technological issues that impact Arizona's ability to become a global leader in solar power innovation, development and deployment. Multi-disciplinary research efforts and capabilities at Arizona State University and the University of Arizona are being utilized in close collaboration with partners from industry and government in the creation and use of Az SMART.

The goal of the three-year project is to develop a unique analysis tool, tailored to the examination of a successful roll-out of large-scale solar energy infrastructure in Arizona, and the required electric grid technologies to enable that infrastructure.

The principal outputs of the project are Solar Feasibility research, a Solar Scorecard for Arizona, and ultimately, the analytical tool that integrates them into a decision support framework. The end product will be accessible by remote web access (www.azsmart.org), as well as at Decision Theater, a dynamic, immersive visualization environment facility at Arizona State University.

Arizona's Solar Scorecard

Researchers at the L. William Seidman Research Institute of the W. P. Carey School of Business at Arizona State University are developing Arizona's Solar Scorecard. The Solar Scorecard comprises metrics drawn from energy usage forecasts, environmental valuation analyses, economic development analyses, and energy security evaluations. It is assembled from a series of whitepapers which provide the research and analysis to translate commercial and public policy choices into measures of economic, environmental, social and energy security impact on Arizona. These papers will be completed over a three year span, with the first year largely concentrated on utility-scale power generation. The second and third years concentrate on distributed generation and transportation. The 14 whitepapers are as follows:

1. *Energy Sector Technology;*
2. *The Market-Determined Cost of Inputs to Utility-Scale Electricity Generation;*
3. *Incentives and Taxation;*
4. *Regulations and Standards;*
5. *AZ Energy Demand Analysis;*
6. *Present and Future Cost of New Utility-Scale Electricity Generation;*
7. *Energy Usage/ Supply Forecasts;*
8. *Emissions/Pollution Analysis;*
9. *Solar Export Potential;*
10. *Environmental Valuation Analysis;*
11. *Solar Inter-State Competition;*
12. *Economic Development Analysis;*
13. *Impact of Solar Generation upon Arizona's Energy (Electricity) Security;*
14. *The Determinants of the Financial Return from Residential Photovoltaic Systems*

About This Paper

This white paper is part of a series of 14 papers that make up the Az SMART Solar Scorecard.

The primary goal of this paper is to examine the electricity security implications for Arizona if more solar is added to the state's electricity generation mix. The paper initially attempts to adapt two contemporary measures of energy security for the narrower concept of electricity security, but abandons that strategy due to sourcing and interpretative issues, in favor of a monetization approach based upon a series of risks and mitigations applicable to Arizona.

As Az SMART progresses, the data sources and estimates featured within this paper will be updated; and further testing of the monetization approach to electricity security will be implemented to confirm its applicability for inclusion in the Az SMART utility-scale tool.

Executive Summary

- The paper proposes a new approach for numerically assessing electricity security in Arizona, premised upon monetization.

- The concept of energy security has developed over time from a narrow, initial focus upon the national implications of oil imports to something far more wide-ranging that touches upon the self-sufficiency, reliability, affordability and sustainability of energy supply.

- Despite the presence of common themes within the literature, a quantifiable measure of energy security as a standard, composite series of metrics is rare.

- Sovacool and Brown (2010) and the Institute for 21st Century Energy (2010) have both developed contemporary, quantifiable measures of energy security. However, their indices contain data discrepancies and subjective measures, implement crude or questionable scoring techniques, overlook key areas, and focus exclusively upon the nation state, to the detriment of state-level energy policy, but are nevertheless of value as a starting point for the development of a narrower electricity security index focused specifically on Arizona.

- The paper initially identifies 12 metrics of potential relevance for Arizona's electricity security across four dimensions from the 2010 studies. These are availability, affordability, efficiency and environmental stewardship. Availability refers to the accessibility and reliability of electricity supply, and the range of generating fuel sources. Affordability refers to the equitable access of energy services and stable prices. Efficiency refers to the minimization of consumption through technological advances, or for behavioral reasons. Environmental stewardship addresses the sustainable consequences of producing electricity from a particular fuel source.

- Each metric is examined in turn, without making any initial assumptions about their potential aggregation as a composite index. This highlights difficulties in sourcing relevant, quantifiable data, with clearly defined inputs and outputs for electricity security metrics. It also leads to the conclusion that meaningful results are not always possible, even when appropriate data can be sourced, prompting the new monetization approach.

The 12-Metric State Electricity Security Measure Initially Proposed by this Paper

Availability	**Affordability**
• Diversification of Electricity Sources • Electricity Capacity Margins • Electricity Transmission Line Mileage	• Retail Residential Prices • Electricity Price Volatility
Efficiency	**Environmental Stewardship**
• Electricity Expenditure per GDP • Electricity Consumption per Capita	• SO_2 Emissions • CO_2 Emissions • NO_X Emissions • Land Resource Requirements • Water Usage

Source: Authors

- This monetization proposal acknowledges the relevance of the issues highlighted by the 12 metrics for electricity security, but repositions them as risks or mitigating factors, thereby allowing for a numeric measurement of electricity security at a state level.

- The monetization component primarily relates to the mitigating factor(s) needed to offset risk(s).

- Five broad types of risk are proposed as being of relevance to Arizona's electricity security. These relate to pricing, system/infrastructure, raw fuel supply, environmental issues and end-user demand.

- Pricing risks are price volatility, price rises and government regulation (such as the introduction of a carbon tax). Mitigating factors for these risks are diversification or changes to generation mix sources, and energy efficiency measures.

- System/infrastructure risks include transmission grid or power plant failure, capacity overload and government regulations. Mitigations for these risks include infrastructure investments, increasing spare capacity at peak load, encouraging small-scale distributed generation, diversifying the generation mix to include a greater emphasis upon renewables, and energy efficiency measures.

- Raw fuel supply risks include dependency on external fuel suppliers, intermittency and increased competition for energy. The mitigations proposed are hedging or long-term agreements, investing in back-up generation, technological advances, diversifying generation mix sources, and greater use of local generation mix fuels.

- Environmental risks for Arizona's electricity security include emission levels and water usage. The mitigating factors include diversification of the generation mix, encouraging small-scale distributed generation, technological advances, and energy efficiency measures.

- End-User risk primarily refers to customer power demand increases (temporary or longer-term). The mitigations proposed for this risk are energy efficiency measures, increased reliance on local generation fuels, and increasing spare capacity at peak load.

- To understand the value of a monetization strategy, the hypothetical impact of rising coal prices in 2010 is considered with reference to the 2009 Arizona electricity generation mix.

- Focusing exclusively on a price rise risk, this shows how exposure to a 5 percent increase in the direct cost of coal for electricity generation can be offset by mitigations, such as the combination of an efficiency initiative resulting in 1 percent less MBtu consumed per capita, and a generation mix change in which 2.5% of the 2009 coal-generated electricity consumption switches to solar thermal/PV.

- The delta for the hypothetical example is 2% less than the 2010 base case for the cost of raw fuel costs met by the total electricity sector, and would actually result in a 0.15% year-on-year fall of total raw fuel costs in 2010, all other things being equal.

- This direct fuel cost saving for the industry, if passed on to end-users, would help stabilize or reduce retail prices, and therefore exert a positive influence on electricity security.

Monetization of Electricity Security – Hypothetical Example

ELECTRICITY SECURITY RISK	EXPOSURE	MITIGATIONS	COST
End-User Price Rise	5% increase in the direct cost of coal	• 1% less MBtu consumed per capita • 2.5% switch from coal-generated electricity consumption to solar thermal/PV	• Delta is 2% less than the 2010 base case of $2,066 million • Total raw fuel costs fall, year-on-year, by 0.15%

Source: Authors

- Despite the simplicity of circumstances considered within this hypothetical example, the monetization approach does appear to be of value for numerically assessing electricity security within Arizona.

- Subject to further testing, a monetization approach to electricity security is therefore recommended for inclusion within the Az SMART utility-scale tool.

Table of Contents

List of Tables

List of Figures

List of Acronyms

Abbreviation	*Definition*
Entities	
ACC	Arizona Corporation Commission
APERC	Asia Pacific Energy Research Centre
APS	Arizona Public Service Company
CPUC	California Public Utilities Commission
DOE	Department of Energy
DOT	Department of Transport
DSIRE	Database of State Incentives for Renewable Energy
EIA	Energy Information Administration
FHA	Federal Housing Administration
G8	Group of 8 Governments
OECD	Organization for Economic Co-operation and Development
SRP	Salt River Project Power and Water
TEP	Tucson Electric Power
UN	United Nations
WECC	Western Electricity Co-ordinating Council
Other Terms	
Btu	British thermal units
CO_2	Carbon Dioxide
GDP	Gross domestic product
GWh	Gigawatt hour
HHI	Herfindahl-Hirschman Index
kV	Kilovolt
kW	Kilowatt
kWh	kilowatt hour
MBtu	Million British thermal units
MW	Megawatt
MWh	Megawatt hour

Abbreviation	*Definition*
NO_X	Nitrous oxide
O&M	Operations and maintenance
PSM	Power Supply Margin
PV	Photovoltaic
R&D	Research and Development
RES	Renewable Energy Standard
RMR	Reliability must run
RPS	Renewable Portfolio Standard
SO_2	Sulfur Dioxide
SUV	Sport utility vehicle
VMT	Vehicle miles traveled

1. Introduction

Over the past 40 years, politicians, policy makers and energy analysts have increasingly referred to the concept of 'energy security'. However, what does the term mean, and to what extent will the development and deployment of renewable energy sources, such as solar power, affect energy security?

Focusing primarily upon Arizona, the objectives of this paper are to:

- Review the energy security literature as a stepping stone to the development of a series of metrics of relevance for the narrower concept of electricity security within the state.
- Assess the electricity security implications for Arizona if more solar is added to the state's electricity generation mix.
- Develop or propose a means of assessing electricity security for inclusion within the Az SMART utility-scale tool.

Beginning with some definitions of the wider concept of energy security, the paper will trace the history and evolution of concept, including potential ways in which the latter can be quantitatively measured. Two contemporary quantitative measures of energy security will be critiqued to highlight their strengths and weaknesses as indices in their own right, and also discuss their potential relevance for electricity security within Arizona. This will lead to the identification of a series of 12 metrics potentially applicable to an analysis of electricity security within a state.

The identification of this third series of metrics is not intended to reduce discussions of energy security to electricity generation issues. That is far too restrictive for such a multi-dimensional concept. It is simply to focus upon aspects of greatest relevance for different levels of solar within Arizona's electricity generation mix.

Applying each of the 12 metrics individually to Arizona to assess their relevance for electricity security within the state, the SMART[1] framework for objectives or goal-setting will be applied to the metrics as part of the index development process. SMART is an acronym standing for:

- Specific: clear and focused, to avoid misinterpretation.
- Measurable: based upon consistent, quantifiable data, with clearly defined inputs, outputs and/or impacts.
- Actionable: inexpensive to collect or calculate, in terms of time and money.
- Relevant: utilizes objective industry benchmarks and commonly referenced research.
- Timely: grounded within a specific timeframe.

The application of SMART to the 12 metrics leads to the conclusion that:

- It is not always possible to source relevant, quantifiable data, with clearly defined inputs and outputs for some electricity security metrics.
- Even when appropriate data can be found, the results sometimes fail to offer meaningful insight for a state's level of electricity security.

The paper then proposes an alternative index development strategy, namely the monetization of electricity security and repositioning of the 12 metrics as either risks to, or mitigations for, electricity security in Arizona.

2. Energy Security: Origins, Definition and Evolution of the Concept

Yergin (2006) suggests that the term 'energy security' first came to the fore as a question of national strategy when, on the eve of the First World War, the First Lord of the Admiralty shifted the power source of the British navy from Welsh coal to Persian oil. Sovacool and Brown (2010) argue that every US Presidential administration since Carter has viewed national security and energy supply as being "… inexorably intertwined" (p. 79). Energy security was

[1] This should not be confused with Az SMART.

top of the agenda when the G8 met in St Petersburg in July 2006; and the United Nations Division for Sustainable Development in 2009 advocated the promotion of new and renewable sources of energy to enhance energy security.[2] However, what does the term 'energy security' actually mean?

Ciută (2010) argues that there have been few attempts to define the concept, despite the energy domain being saturated with the language of security.[3] Nevertheless, a survey of academic and policy literature suggests that the concept of energy security has developed over time from a narrow focus upon oil imports to something far more wide-ranging.

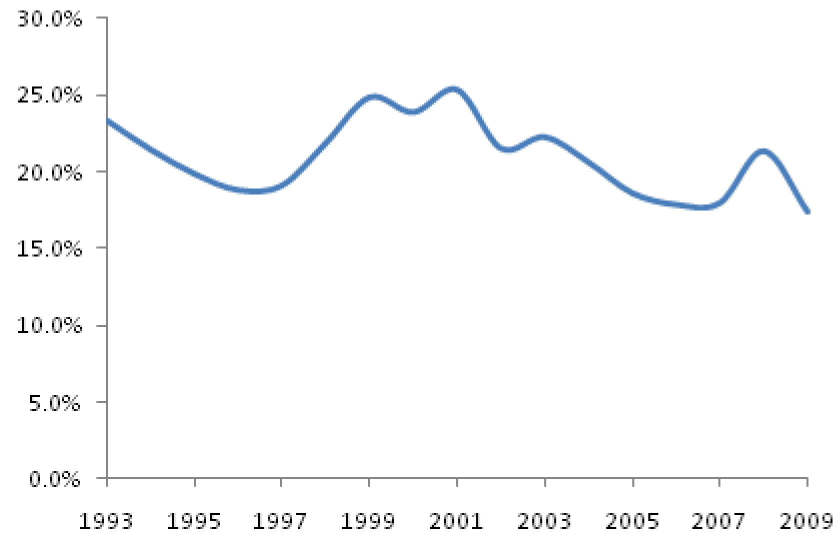
Initially, in the United States, energy security simply referred to the extent to which the nation was dependent upon foreign oil, and, in particular, imports from the Middle East. For example, President Carter issued a famous declaration in 1980 that any blockade of oil from the Persian Gulf would be viewed as an assault on the vital interests of the United States and hence repelled by any means necessary, including military action (Sovacool and Brown, 2010). U.S. energy security policies at this time therefore included the reduction of oil imports and the management of any risks associated with those imports (IEA, 2002), prompting the Bush Senior, Clinton and Bush Junior administrations to spend billions of dollars protecting oil resources in the Persian Gulf. The closest thing to an actual measure for U.S. energy security at this time is therefore a graph to show the percentage trend, and cost, of foreign oil imports over time.

Yergin (2006) traces this oil-based conceptualization of energy security back to the oil crisis of 1973; and since that time, energy security appears to have become increasingly linked with energy independence. For example, much of the political rhetoric of the Bush Junior administration, 2001-2008, emphasized the need to reduce dependence upon oil from the Middle East, and increase the stability of the nation's supply by boosting domestic production and developing alternative energy sources (Bonnefille, 2008). A working paper recently issued by the Council on Foreign Relations also describes energy security as "… mainly a challenge

[2] UN-DESA (2009). 'Sustainable Development: Promotion of New and Renewable Sources of Energy – Report of the Secretary-General', downloaded December 14, 2010 from: http://www.un.org/esa/dsd/resources/res_pdfs/ga-64/briefings/EU_Brief.pdf
[3] Ciută (2010), p.124.

related to oil" (p.8).[4] Figure 1 uses this simple equation of energy security with oil imports to illustrate how the U.S. has reduced the percentage of its total oil imported from the Persian Gulf during the first decade of the twenty first century.

Figure 1: Percentage of Annual U.S. Net Imports of Persian Gulf Crude Oil and Petroleum



Source: EIA (2010b) [5]

However, other dimensions of energy security have also emerged that call into question the amount and cost of foreign oil imports as an effective energy security index. For example, Yergin describes how energy security concerns have extended beyond oil to the reliability of the electricity supply system, as demonstrated by power black outs in the West and chronic shortages of electric power in developing countries. This suggests that an effective energy security index also requires a metric to measure the reliability of the electricity system alongside the foreign oil import trend. One potential option is an adaptation of WECC's annual power supply assessments, or a metric to calculate the amount of available capacity of U.S. electric power system at peak load, expressed as a percentage of total peak capability.

[4] Levi, M. (2010). 'Energy Security: An Agenda for Research', Council on Foreign Relations Working Paper, New York: Council on Foreign Relations
[5] http://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PETands=MTTNTUSPG2andf=A (7/29/10)

A 2003 National Conference of State Legislatures report equated energy security with resilience, before focusing primarily on accidents, natural disasters, and a post 9/11 threat of terrorist or intentional damage, which suggests that one or more metrics is needed, focused upon the security and ability of energy supply lines to withstand natural and manmade events. The World Bank Group (2005) proposed an interpretation of energy security based upon energy efficiency, diversification of supply (encompassing both type and origin) and minimization of price volatility; and a literature review suggests that this latter conceptualization has become more widespread. Consider, for example, Table 1, which lists 18 definitions of energy security. The common terms that stand out within these definitions include sufficiency, reliability, stability, affordability and sustainability.

Sufficiency refers to the extent to which a country can meet its energy demands via domestic and imported sources. Key potential metrics for an energy security index perspective therefore include the domestic availability of specific energy sources (coal, natural gas, nuclear, oil, and renewables), and the percentage of energy fuel imports.

The reliability of energy supply assumes the uninterrupted supply of energy, whenever and wherever it is needed within a country. This will require the inclusion of metrics on a par with WECC's electricity power supply assessments in an energy security index, addressing the ways in which different forms of energy are delivered safely and reliably to end-users.

Stability or affordability refers to pricing. Alhajji (2007) argues that stable pricing can only happen if energy-exporting and importing counties cooperate to ensure the security of supply and demand simultaneously. Key metrics of potential value here include energy expenditure per GDP or household, and the volatility of specific energy prices over time.

Sustainability is a relatively recent addition to the energy security literature, and refers to the potential environmental effects of energy security actions and disruptions. Sustainability metrics of potential value for an energy security index therefore include emission level trends, land and water usage.

Table 1: Contemporary Definitions of Energy Security

Author/Source	Definition
Ahamed (2011)	"… the uninterrupted physical availability at a price which is affordable, while respecting environment concerns". Energy security may also be defined as "the availability of usable energy supplies, at the point of final consumption, in sufficient quantity and timeliness so that, given due regard for encouraging energy efficiency, the economic and social development of the country is not materially constrained"[6]
Aimone (2009)	"… energy security encompasses sufficiency, surety and sustainability."
Alhajji (2007)	"Definitions of energy security range from uninterrupted oil supplies to the physical security of energy facilities to support for biofuels and renewable energy resources."
APERC (2003)	"… securing adequate energy supplies at reasonable and stable prices in order to sustain economic performance and growth." (p. 4)
Bielecki (2002)	"… reliable and adequate supply of energy at reasonable prices" (p.237)
Bird (2007)	"… ensuring security of supply of fossil fuels (but keeping climate change in mind), finding alternative sources of energy and reducing demand for energy" (p.5)
Brown, Rewey and Gagliano (NCSL) (2003)	"Energy security refers to a resilient energy system" (p.7)
Ethanol across America (2005)	"Do we mean national security? Well sort of. …energy independence? Well, sort of that too. Do we mean economic security? Yes, all of the above." (p.1)
European Commission (2000)	"… uninterrupted physical availability of energy products on the market, at a price which is affordable for all consumers (private and industrial)"
IEA (2011)	"… the uninterrupted physical availability at a price which is affordable, while respecting environment concerns"[7]

[6] http://www.neopanora.com/en/developing-countries/113.html
[7] http://www.iea.org/subjectqueries/keyresult.asp?KEYWORD_ID=4103

Institute for 21st Century Energy / U.S. Chamber of Commerce (2010a)	"… the reliable supply of affordable energy." (p.14)
Ocheltree (2009)	"A more comprehensive notion of energy security should take into account three principles that supersede the objective of independence: resilience, diversity of supply and global interdependence" [8]
Ölz, Sims and Kirchner (2007)	"the degree of probability of disruption to energy supply occurring" (p.13)
Sovacool and Brown (2010)	"…composed of availability, affordability, efficiency and environmental stewardship" (p. 9.1)
Ahamed (2011)	"the uninterrupted physical availability at a price which is affordable, while respecting environment concerns". Energy security may also be defined as "the availability of usable energy supplies, at the point of final consumption, in sufficient quantity and timeliness so that, given due regard for encouraging energy efficiency, the economic and social development of the country is not materially constrained"[9]
Westminster Energy Forum (2006)	"…covers many concerns linking energy, economic growth and political power" (p.9)
White (2010)	"… a shorthand term for the broad debate among policy makers, academics and independent energy experts about what steps the U.S. should take to reduce its vulnerability to oil-price shocks, geopolitical pressures on energy supplies, climate-change risks and disruptions to domestic electricity prices." (p. A4)
World Bank Group (2005)	"… energy security means ensuring countries can sustainably produce and use energy at reasonable cost in order to: - Facilitate economic growth and, through this, poverty reduction; and - Directly improve the quality of peoples' lives by broadening access to modern energy services." (p.3)
Yergin (2006)	"… the availability of sufficient supplies at affordable prices." (p.69)

Source: Authors

[8] http://www.globalization101.org/index.php?file=issueandpass1=subsandid=327
[9] http://www.neopanora.com/en/developing-countries/113.html

The key thing to note, however, is that energy insecurity does not necessitate an energy crisis. It merely increases the risk of a crisis happening.

3. Operationalizing Energy Security – Two Contemporary Measures

Despite the presence of common themes within the literature, the operationalization of energy security as a standard, composite series of SMART, evaluatory metrics appears to have only come to the fore when two quantifiable measures were developed by Sovacool and Brown (2010) and the Institute for 21st Century Energy (2010).

One potential reason for the absence of quantifiable measures is provided by Ocheltree (2009), who concludes that the definition of energy security has to differ from country to country, as illustrated by his definitions of energy security for the following four countries:

- ***USA:*** " … producing energy at home and relying less on foreigners."
- ***China:*** " … buying stakes in foreign oil fields."
- ***Russia:*** " … restrictions on foreign investment in domestic oil and natural gas."
- ***Japan:*** " … offsetting … scarcity of domestic resources through diversification, trade and investment."[10]

3.1. Sovacool and Brown's (2010) Operationalization

Drawing from a review of 91 academic papers published between 2003 and 2008, Sovacool and Brown propose an energy security index consisting of 10 metrics, divided across 4 multi-dimensional categories – availability, affordability, economic efficiency and environmental stewardship. Sovacool & Brown's index metrics are shown in Table 2.

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[10] http://www.globalization101.org/index.php?file=issueandpass1=subsandid=327

Availability references are found within 80% of the papers reviewed by Sovacool and Brown, who subsequently suggest that metrics addressing the procurement of a sufficient and uninterrupted supply, a limited dependency on foreign fuels, and the need for a mix of energy sources, suppliers and locations to safeguard against sabotage or attack are all of value. However, Sovacool and Brown's energy security index actually only contains 3 availability metrics, and these are exclusively focused upon the degree of reliance on foreign fuel supplies.

Table 2: Sovacool and Brown's Energy Security Index Metrics

Availability	Affordability
• Oil Import Dependency • Natural Gas Import Dependency • Dependence on Petroleum Transport Fuels	• Retail Residential Prices • Retail Gasoline/Petrol Prices
Efficiency	**Environmental Stewardship**
• Energy Intensity • Per Capita Electricity Use • On-Road Fuel Intensity of Passenger Vehicles	• SO_2 emissions • CO_2 emissions

Source: Sovacool and Brown (2010)

Affordability issues are common to over half of the papers reviewed by Sovacool and Brown. Encapsulating the equitable access of energy services, stable pricing and access to a broad range of high-quality energy fuels, Sovacool and Brown propose residential and transportation metrics as indicators of affordability on the grounds that they represent the greatest use of energy by the general population.

Economic efficiency is Sovacool and Brown's third dimension. This refers to the minimization of resource units needed per unit of output through substitution or changing habits, along with innovative service quality improvements to reduce any negative externalities or costs associated with energy supply and use. Two of their metrics for this dimension indicate efficiency of individual technologies at an end-user level. The other (energy intensity) correlates energy use with economic output across multiple sectors.

Sovacool and Brown's final category, environmental stewardship, appears in approximately one quarter of the papers reviewed. Emphasizing sustainability, sulfur dioxide (SO_2) and carbon dioxide (CO_2) emission level metrics are proposed by Sovacool and Brown as part of their energy security index.

Each metric is given equal weighting within Sovacool and Brown's index and inversely measures energy security. That is, the higher the value of a metric, the lower the energy security.

To test their operationalization, Sovacool and Brown evaluate the energy security of 22 OECD countries between 1970 and 2007. They assess a country's relative progress by assigning a value of -1 if the indicator worsens over time, 0 if it stays the same and +1 if it improves. This simple scoring exercise therefore prevents large changes in any indicator from dominating their measure of relative progress. However, it also means that a minute change in one indicator has the same influence as a large change in another – a potential flaw in their calculations.

To show how countries perform relative to others, and also account for the impact of country-specific energy policies and resource endowments, z-scores are calculated for each metric, subtracting mean value from each data point and dividing by the metric's standard deviation.[11]

Focusing specifically upon the U.S., 1970-2007, Sovacool and Brown conclude that:

- Only Greece, Spain and Portugal have performed worse than the U.S. over the 37 years.
- The U.S. has made some progress in terms of energy intensity, fuel economy and SO_2 emissions.
- However, the U.S. has also become the world's largest oil consumer at a time when domestic production plummeted, leading to a rise in oil imports from 22% to 59% of total consumption. This increased dependence on foreign supplies of natural gas and oil has also necessitated extensive and costly diplomatic and military efforts to safeguard imports from insecure or politically unstable countries.

[11] Z-scores are a statistical reference to the Normal distribution.

- Susceptibility to oil disruptions and pricing spikes is greater than ever.
- The adoption of more energy efficient technologies has restricted consumption to an increase of 23% at a time when U.S. economic output increased by 65% and per capita incomes by 35%.
- U.S. aggregate demand for electricity rose by 170% between 1970 and 2007, with electrical power usage growing from 25% of the nation's total energy use to 40%.
- SO_2 emissions from electrical generators have fallen, but the U.S. has experienced a rise in respiratory illnesses in part due to vehicle and coal-burning plant pollution.
- The U.S. remains the world's leading emitter of greenhouse gases.

At a generic, global level, Sovacool and Brown also conclude:

- Most of the countries analyzed have regressed in terms of their energy security, despite the growth in renewable portfolio standards, feed-in tariffs, emissions trading schemes and investments in alternative fuels.
- There is significant disparity between countries.
- No country has scored perfectly on the index, because energy efficiency measures usually focus on meeting the demands of consumers, rather than reducing that demand. That is, developing or producing more energy efficient goods and services, rather than encouraging people to change their behavior.
- Domestic action to change consumer behavior, promote energy efficiency and lower greenhouse gas emissions is just as important as alliances and interactions with energy resource-producing countries.

3.2. Institute for 21st Century Energy's (2010) Operationalization

The Institute for 21st Century Energy and U.S. Chamber of Commerce (2010a; 2010b) propose an alternative energy security index consisting of 37 metrics, split across 9 categories, to measure the perceived reliability and diversity of U.S. supplies, 1970-2030.

Table 3: Institute's Metric Categories, Descriptions and Constituent Measures

Category	Description	Constituent Measures
Global Fuels	The higher the reliability and diversity of global reserves and supplies of oil, natural gas and coal, the lower the risk to energy security.	• Security of World Oil Reserves • Security of World Oil Production • Security of World Natural Gas Reserves • Security of World Natural Gas Production • Security of World Coal Reserves • Security of World Coal Production
Fuel Imports	The lower the exposure of the U.S. economy to unreliable and concentrated supplies of oil and natural gas, and the lower the import costs, the lower the risk to energy security.	• Security of World Petroleum Imports • Security of World Natural Gas Imports • Oil and Natural Gas Import Expenditures • Oil and Natural Gas Import Expenditures per GDP
Energy Expenditure	The lower the energy costs to the U.S. economy and less the consumer exposure to price shocks, the lower the risk to energy security.	• Energy Expenditures per GDP • Energy Expenditures per Household • Retail Electricity Prices • Crude Oil Prices
Price and Market Volatility	The lower the susceptibility of the U.S. economy and consumers to large swings in energy prices, the lower the risk to energy security.	• Crude Oil Price Volatility • Energy Expenditure Volatility • World Oil Refinery Utilization • Petroleum Stock Levels
Energy Use Intensity	The lower the energy usage of industry, commercial and residential customers, the lower the risk to energy security.	• Energy Consumption per Capita • Energy Intensity • Petroleum Intensity • Household Energy Efficiency • Commercial Energy Efficiency • Industrial Energy Efficiency
Electric Power Sector	The greater the reliability and diversity of electricity generating capacity, the lower the risk to energy security.	• Electricity Capacity Diversity • Electricity Capacity Margins • Electricity Transmission Line Mileage
Transportation Sector	The greater the efficiency of the auto fleet and diversity of fuels, the lower the risk to energy security.	• Passenger Car Average MPG • Transportation Vehicle Miles Traveled per GDP • Transportation Non-Petroleum Fuel Use
Environmental	The lower the number of Greenhouse Gas emissions reduction mandates, and lower the energy CO_2 emissions, the lower the risk to energy security.	• Energy-Related CO_2Emissions • Energy-Related CO_2Emissions per Capita • Energy-Related CO_2 Emissions Intensity • Non CO_2 Emitting Share of Electricity Generation
Research and Development	The higher R&D investments in new energy technologies and greater the number of technical graduates, the lower the risk to energy security.	• Industrial Energy R&D Expenditures • Federal Energy and Science R&D Expenditures • Science and Engineering Degrees

Source: Institute for 21st Century Energy (2010a)

The Institute's 9 categories are:

- Global Fuels
- Fuel Imports
- Energy Expenditures
- Price and Market Volatility
- Energy Use Intensity
- Electric Power Sector
- Transportation Sector
- Environmental
- Research and Development

Each category contains 3 to 6 constituent metrics, covering a wide range of energy supply, end-use, operations and emissions issues. Descriptions for each metric and its constituent measures are displayed in Table 3. The data sources for each constituent measure, drawn from historical records and EIA forecasts, are shown in Table 4. These 37 measures are then reduced to 4 sub-indices. These are the geopolitical, economic, reliability and environmental.

The geopolitical sub-index examines:

- U.S. dependence upon fuel imports.
- The political stability and attitudes of the countries supplying the imports.
- Associated political/military risks.

The economic sub-index addresses:

- The percentage of national income spent on energy.
- Price volatility.
- The impact of rising prices upon national wealth/trade balances.

The reliability sub-index relates to:

- The high costs of disruptions to energy supplies.
- Vulnerability to accidents or sabotage.
- Generation or capacity shortages and outages.

Table 4: Data Sources for Each Constituent Measure

Constituent Measures	Data Source
Security of World Oil Reserves	Global oil reserves weighted by Freedom House Freedom Index and HHI[12]
Security of World Oil Production	Global oil production weighted by Freedom House Freedom Index and HHI
Security of World Natural Gas Reserves	Global natural gas reserves weighted by Freedom House Freedom Index and HHI
Security of World Natural Gas Production	Global natural gas production weighted by Freedom House Freedom Index and HHI
Security of World Coal Reserves	Global coal reserves weighted by Freedom House Freedom Index and HHI
Security of World Coal Production	Global coal production weighted by Freedom House Freedom Index and HHI
Security of World Petroleum Imports	Net petrol imports as % of total U.S. supply weighted by Freedom House Freedom Index and HHI
Security of World Natural Gas Imports	Net natural gas imports as % of total U.S. supply weighted by Freedom House Freedom Index and HHI
Oil and Natural Gas Import Expenditures	Value of net imports of oil, petroleum and natural gas in billions of real (2000) dollars
Oil and Natural Gas Import Expenditures per GDP	Value of net imports of oil, petroleum and natural gas as a % of GDP
Energy Expenditures per GDP	Total real (2000) dollar cost of energy consumed per $1,000 of GDP per year
Energy Expenditures per Household	Total real (2000) dollar cost of energy consumed per household per year
Retail Electricity Prices	Average U.S. electricity costs in cents per kWh in real (2000) dollars
Crude Oil Prices	Average U.S. cost per barrel of crude oil in real (2000) dollars
Crude Oil Price Volatility	Annual change in real (2000) crude oil prices averaged over a 3 year period
Energy Expenditure Volatility	Average annual change in real (2000) U.S. energy expenditures per $1,000 of GDP
World Oil Refinery Utilization	Average % utilization of global petroleum refinery capacity (BP Statistical Review)
Petroleum Stock Levels	Average day's supply of petroleum stocks
Energy Consumption per Capita	Million Btu consumed per year
Energy Intensity	Million Btu of primary energy used in the economy per $1,000 of real (2000) GDP
Petroleum Intensity	Million Btu of petroleum consumed per $1,000 of real (2000) GDP
Household Energy Efficiency	Million Btu of total energy consumed per household

[12] HHI = Herfindahl-Hirschman Index

Table 4 (continued): Data Sources for Each Constituent Measure

Constituent Measures	Data Source
Commercial Energy Efficiency	Million Btu of total commercial energy consumed per 1,000 square feet of commercial floor space
Industrial Energy Efficiency	Trillion Btu of total industrial energy consumed per unit of industrial production, measured by the IP Index
Electricity Capacity Diversity	Market share concentration index (HHI) of the primary categories of electric power generating capacity, adjusted for availability
Electricity Capacity Margins	Unused available capacity of U.S. electric power system at peak load as % of total peak capability
Electricity Transmission Line Mileage	Current miles of transmission lines per gigawatt of summer demand
Passenger Car Average MPG	Average miles per gallon of passenger car fleet
Transport Vehicle Miles Traveled per GDP	Vehicle miles traveled (VMT) per $1,000 of GDP in real (2000) dollars (DOT/FHA for VMT; EIA)
Transportation Non-Petroleum Fuel Use	Non-petroleum fuels as % of total U.S. transportation energy consumption
Energy-Related CO_2Emissions	Total US energy related CO_2 emissions in million metric tons
Energy-Related CO_2Emissions per Capita	Million metric tons of CO_2 emissions from energy per capita
Energy-Related CO_2 Emission Intensity	Metric tons of CO_2 emissions from energy per $1,000 of GDP in real (2000) dollars
Electricity Non CO_2 Generation Share	% of total electric power generation contributed by renewables, hydroelectric, nuclear and fossil-fuel plants with CCS technology
Industrial Energy R&D Expenditures	Dollars of industrial energy related R&D (non-Federal) per $1,000 of GDP
Federal Energy and Scientific R&D Expenditures	Dollars of federal energy and science R&D, per $1,000 of GDP
Science and Engineering Degrees	Number of science and engineering degrees, per billion dollars of real (2000) GDP – IPEDS survey

Source: Institute for 21st Century Energy (2010b)

The environmental sub-index focuses on:

- Climate change.
- Emissions levels.

To ensure uniformity of measurement and help preserve underlying trends, the Institute for 21st Century Energy normalizes each metric by setting the value for 1980 at 100, before stating all other values in proportion to this. 1980 is selected because the Institute suggests it is the worst year for U.S. energy security as a composite index since 1970. However, it is not necessarily the worst year for energy security as a whole, for individual metrics or the sub-indices. A potential alternative to this, not explored by the Institute, might be to monetize the metrics.

The 37 metrics are then assigned to one or more sub-indices, as shown in Table 5, and a weighting applied to each metric based upon "analysis" and "expert judgment" (2010a, p.44), neither of which are defined or explained. This results in a weighted average score per sub-index. The sub-indices are then merged into a composite or total index. The geopolitical and economic sub-indices each account for 30% the composite index because they "… dominate much of the public debate on energy security." (2010a, p. 45). The reliability and environmental sub-indices account for 20% each.

A lower value for the composite index is described as representing an improvement in energy security and a higher value described as deterioration. On the few occasions where this does not make sense, the Institute simply flips the scores for those metrics. They also acknowledge transforming the non-linearity of some metrics, but fail to provide specific examples.

Arguing that metrics focusing exclusively on oil only explain part of energy security, the Institute for 21st Century Energy identify three primary uses for their index. These are:

- To provide a historical overview of U.S. energy security that identifies key trends.
- To assess the potential impact of new policies on U.S. energy security.
- To provide insights for focusing policies.

Applying their index to the U.S., they describe the 1970s as a time of unexpected geopolitical crises, culminating in supply disruptions and soaring fuel prices. The 1980s are described as a decade of greater energy security, with a 24% decline in risk due to improvements across all 4 sub-indices and most constituent metrics. This enhanced level of security continues up to and including 1994, before the following factors thereafter negatively affect U.S. energy security:

- A steady decline in U.S. oil production.
- An increased reliance upon oil from countries with low Freedom Index rankings.
- A rise in the global trade of natural gas.
- Increased reliability risks associated with the electric power sector.
- A shift from passenger cars to SUVs, and an increase in the average miles driven.
- A steep rise in energy-related CO_2 emissions from fossil fuels.
- A decline in R&D investments and number of Science/Engineering graduates.

The Institute concludes that energy security risks have continued to increase during the first decade of the 21st century due to extreme price volatility in the oil markets, rising natural gas prices, increasing reliance on fuel imports and the fragility of the transmission system. This latter fragility is best demonstrated by the Northeast Blackout of 2003 which left an estimated 55 million Americans without power.

Looking to the future, the Institute's index suggests that the main threats to energy security up to 2030 are price and expenditure rises, driven by geopolitical and economic impacts upon the increasing cost of oil and gas. However, these increases could be counteracted by an ample and stable supply of transportation fuels and electricity sources, greater energy efficiency in all sectors, and continued diversification.

Table 5: Metric Components by Sub-Index with Weighting (expressed as a percentage)

	Geopolitical	Economic	Reliability	Environmental
Security of World Oil Reserves	4	2	2	
Security of World Oil Production	7	4	7	
Security of World Natural Gas Reserves	4	2	4	3
Security of World Natural Gas Production	4	2	3	4
Security of World Coal Reserves	3			4
Security of World Coal Production	2			3
Security of World Petroleum Imports	6	2	9	
Security of World Natural Gas Imports	2	1	2	
Oil and Natural Gas Import Expenditures	6	6		
Oil and Nat. Gas Import Expenditures/GDP		9		
Energy Expenditures per GDP	4	7		
Energy Expenditures per Household		9		
Retail Electricity Prices		6		
Crude Oil Prices	16	14	9	
Crude Oil Price Volatility	5	3	10	
Energy Expenditure Volatility		4	13	4
World Oil Refinery Utilization	3		6	
Petroleum Stock Levels	2		4	
Energy Consumption per Capita	2	3		5
Energy Intensity	2	4		9
Petroleum Intensity	11	4		5
Household Energy Efficiency		3		2
Commercial Energy Efficiency		2		2
Industrial Energy Efficiency		3		2
Electricity Capacity Diversity			6	3
Electricity Capacity Margins		1	6	
Electricity Transmission Line Mileage		1	6	3
Passenger Car Average MPG	5	3		13
Transportation Vehicle Miles Traveled per GDP	2	1		8
Transportation Non-Petroleum Fuel Use	3		4	4
Energy-Related CO_2 Emissions	1	1		4
Energy-Related CO_2 Emissions per Capita				5
Energy-Related CO_2 Emissions Intensity	4			5
Electricity Non CO_2 Generation Share			5	8
Industrial Energy R&D Expenditures		1		1
Fed Energy & Science R&D Expenditures	1	1	1	1
Science and Engineering Degrees	1	1	3	2

Source: Institute for 21st Century Energy (2010b)

3.3. Critique of Both Operationalizations from an Energy Security Perspective

The two 2010 energy security indices described in Section 3 are open to a number of criticisms.

One criticism relates to the data used by both indices. For example, Sovacool and Brown openly acknowledge data timing and availability deficiencies. Their index only sources energy intensity data for 1980 and 2005. Their fuel economy data is for 2005 and the SO_2 emissions are for 2000 rather than 2007. Sovacool and Brown also describe inconsistencies between the EIA, UN and World Bank, primarily used by their index as data sources, as "… troubling" (p. 89). The Institute for 21st Century Energy uses subjective measures such as the index of democracy and civil liberties for world oil reserve and production calculations.

The arbitrary assignment of weightings to groups or categories of metric in either index is also open to criticism. Sovacool and Brown propose the creation of a simplistic index by equally weighting the different components of energy security and their indicators. The Institute does favor some form of weighting differentiation both within, and between, sub-indices. However, they fail to explain the "analysis" and "expert judgment" used to determine weightings between metrics within a single sub-index; and the Institute also arbitrarily assigns weightings to the summation of each sub-index as a composite, total index based upon the extent to which they dominate public debate about energy security, despite acknowledging that there are no "bright lines" delineating the sub-indices. This has led Michaels (2010), for example, to criticize the Institute's composite index as:

> "… the equivalent of rotisserie baseball. Pick some areas of interest almost at random, measure them in idiosyncratic ways, add up the apples and oranges and declare that the total is something that matters." [13]

Similarly, the crude scoring techniques of both indices are open to criticism. Sovacool and Brown's simple +1, 0 and -1 scoring technique should perhaps be revised to ensure that a minute change in one metric does not exert the same influence as a large change in another.

[13] Downloaded on August 11, 2010 from http://www.masterresource.org/2010/06/the-u-s-chambers-energy-security-index/

The Institute utilizes a variety of linear and non-linear metrics, thereby necessitating the transformation of any non-linearity for scoring purposes, but fails to provide any specific examples. The Institute also adopts a normalization scoring procedure in which the value of each metric is stated in proportion to 1980. There is nothing wrong with their normalization scoring procedure per se. The Institute's choice of year is questionable, though, as 1980 is not even widely recognized as a nadir for energy security.

Sovacool & Brown's energy security index omits key diversification and emission metrics. For example, their index focuses upon oil and natural gas imports, plus transport's dependence upon petroleum, but fails to include the availability of coal, nuclear and renewable energy sources, all of which could mitigate energy security risks from a diversification perspective by limiting a country's dependence upon an energy source. Sovacool and Brown also fail to include other emissions produced by stationary combustion sources for electricity generation, such as NO_X (nitrous oxide), in their narrow equation of environmental stewardship with CO_2 and SO_2 emission metrics, and overlook potential water usage and land resource metrics. The NO_X omission is particularly surprising given the EIA's preference to report all 3 types of emission by electricity generation source in annual state tables, and Environmental Defense's (2002) conclusion that NO_X emissions are the only major criteria air pollutant to have increased since the advent of the modern Clean Air Act in 1970.[14]

By contrast, the Institute for 21st Century Energy's index is possibly too detailed, resulting in inherent duplications (Michaels, 2010). For example, oil-related figures account for approximately half of their index, 4 of the 37 metrics assess CO_2 emissions, and there are also multiple metrics to assess R&D and energy efficiency.

Finally, Sovacool & Brown's unit of analysis is the nation state, thereby overlooking the importance of state-level energy policy decisions; and the Institute's index all too often measures what actually happened, as opposed to the degree of risk at a particular time to energy security, due to their reliance on historical data. The Institute does try to circumvent this

[14] Other major criteria air pollutants identified by Environmental Defense in the report are carbon monoxide, lead, ozone, particulate matter and sulfur dioxide.

problem by developing "… proxies for the risks that could not be measured directly" (2010a, p.42), but fail to provide any examples, detail or explanations for these proxies.

In summary, therefore, the two energy security indices contain data discrepancies and subjective measures, implement crude or questionable scoring techniques, overlook key areas, and focus exclusively upon the nation state, to the detriment of state-level energy policy.

4. Relevance of Either Index for Electricity Security in Arizona

Leaving to one side the general criticisms leveled at both energy security indices in Section 3, to what extent is either measure of relevance for an evaluation of electricity security in Arizona?

To assist with the synthesis and development of an appropriate set of metrics for electricity security at a state level, the SMART mnemonic is used. Variously interpreted by different users, the following definitions are applied within this paper:

- **S**pecific: requires metrics exclusively focused on Arizona's electricity generation mix.
- **M**easurable: requires the metrics to utilize consistent and quantifiable data.
- **A**ctionable: requires the data used by the metrics to be easily accessible.
- **R**elevant: requires the metrics to reflect objective industry benchmarks and situations applicable to Arizona.
- **T**imely: requires the metrics to produce easily interpreted results over time, in accordance with input changes.

The SMART mnemonic therefore suggests that an effective series of electricity security metrics should be specific to electricity generation within Arizona, expressed in a quantifiable, consistent and unduplicated format, and drawn from accessible, objective and widely accepted data, to arrive at meaningful results that change in accordance with the inputs selected.

4.1. Amending the Energy Security Indices for Electricity Security

Based upon this SMART framework, at least 4 of the 10 metrics proposed by Sovacool & Brown, and 13 of the 37 Institute's energy security metrics can be immediately deleted due to their limited relevance for electricity provision within Arizona. Table 6's proposed deletions essentially relate to oil, petroleum and transport issues, as their relevance for electricity, as opposed to energy, security appear to be limited at both a national and state level. The number alongside each metric refers to that metric's position within Sovacool and Brown or the Institute for 21st Century Energy's indices.

In 2009, less than 1% of total electricity generated in the U.S. came from petroleum, underlining the limited national relevance of oil production and imports for electricity security. Coal accounted for 44.46%, natural gas 23.31%, nuclear 20.23%, conventional hydroelectric 6.92%, wind 1.87% and all other sources less than 1% respectively. Ölz, Sims and Kirchner (2007) even suggest that oil no longer plays a major role in electricity production in most OECD countries.[15] In Arizona, 93.87% of electricity generation came from coal, natural gas or nuclear sources, 5.74% conventional hydroelectric, and less than 0.4% from all other fuel sources, including petroleum at 0.06%, thus reinforcing the oil metrics' lack of relevance for electricity security.[16]

A case could potentially be made at a national level to replace the oil metrics with coal/natural gas production and imports, given the importance of both for U.S. electricity generation. However, the relevance of those additions from an Arizona perspective is at best marginal, due to the contractual relationships of state utilities such as APS, SRP and TEP.

Consider, for example, APS, Arizona's biggest utility, who used three main sources for electricity generation – coal, natural gas and nuclear - in 2010. APS benefits from a long term fixed price agreement for coal and nuclear, and a 3-year hedging deal[17] for natural gas, all of

[15] Ölz, Sims and Kirchner (2007), p.20.
[16] EIA (2010a). State Historical Tables – Net Generation by State and Type. Downloaded January 5, 2011 from the EIA website.
[17] Hedging is a risk management strategy used to limit or offset probability of loss from commodity price fluctuations. It is a financial agreement that seeks to reduce an organization's exposure to unwanted risk, as opposed to a means of beating the market, guaranteeing physical supply or necessarily saving money.

which undermine the relevance of import dependency risks for coal and natural gas. APS uses three coal plants at Cholla, Four Corners and Navajo. It holds a 100% stake in three of the four units at Cholla, a 15% stake in two units at Four Corners and a 14% stake in all three units at Navajo. For natural gas, APS has interests in seven gas/oil plants at Yucca, Douglas, Saguaro, Ocotillo, West Phoenix, Redhawk and Sundance. It is difficult, therefore, at least in the short-to-medium term, to apply the import dependency metrics at a state level and hence, by corollary, the world reserve/production metrics.

Table 6: Energy Security Metrics for Initial Deletion from an AZ Electricity Security Index

Potential Deletions from Sovacool & Brown's Energy Security Index	
1	Oil Import Dependency
3	Dependence on Petroleum Transport Fuels
5	Retail/Gasoline Prices
8	On-Road Fuel Intensity of Passenger Vehicles

Potential Deletions from Institute's Energy Security	
1	Security of World Oil Reserves
2	Security of World Oil Production
7	Security of World Petroleum Imports
9	Oil and Natural Gas Import Expenditures
10	Oil and Nat. Gas Import Expenditures per GDP
14	Crude Oil Prices
15	Crude Oil Price Volatility
17	World Oil Refinery Utilization
18	Petroleum Stock Levels
21	Petroleum Intensity
28	Passenger Car Average MPG
29	Transport Vehicle Miles Traveled per GDP
30	Transportation Non-Petroleum Fuel Use

Sources: Institute for 21st Century Energy (2010b), Authors

The transportation metrics featured within Sovacool and Brown or the Institute's energy security indices are also of limited importance for electricity security until hybrid/electrical cars, such as Nissan's all-electric Leaf model, obtain a significant foothold within the Arizona car sales market.

Additional deletions can also be suggested from the Institute's energy security index, to remove the inherent duplication, thereby simplifying the data collection process and ensuring consistency of measurement within Arizona's electricity security metrics. This duplication, which encompasses the affordability, efficiency and environmental stewardship dimensions, is illustrated in Table 7.

Table 7: Duplicating Metrics within the Institute's Energy Security Index

Index Dimension	Index Metric	Description
Affordability	11	Energy Expenditures per GDP
	12	Energy Expenditures per Household
	16	Energy Expenditure Volatility
Efficiency	22	Household Energy Efficiency
	23	Commercial Energy Efficiency
	24	Industrial Energy Efficiency
Environmental Stewardship	31	Energy-Related CO_2 Emissions
	32	Energy-Related CO_2 Emissions per Capita
	33	Energy-Related CO_2 Emissions Intensity
	34	Electricity Non CO_2 Generation Share

Sources: Institute for 21st Century Energy (2010b), Authors

Although the susceptibility of customers to electricity price shocks and changes is clearly of relevance from an affordability perspective, there is considerable overlap between the 3 metrics suggested by the Institute for 21st Century Energy to measure this price volatility. Energy expenditures per GDP and energy expenditure volatility, for example, both measure the magnitude of energy costs within the economy, and the susceptibility of that economy to energy price changes. Energy expenditures per household measures the total real cost, in dollars, of energy consumed per household per year, compared to the consumption per $1,000 of GDP required by the energy expenditure per GDP metric. From a measurement perspective, then, a case can be made to delete two of these three metrics from an electricity security index, and retain the energy expenditures per GDP due to the common ground they all share.

Similarly, the household, commercial and industrial energy efficiency metrics are already covered by two other efficiency metrics common to both contemporary energy security indices.

These are energy consumption per capita and energy intensity, both of which are of value to an assessment of electricity security within a state. The lower the electricity consumption per person per year, or lower the electricity used in the economy per $1,000 of state GDP, the less the demands for power placed upon utilities.

The Institute's energy security index also proposes multiple ways to measure CO_2 emissions, which should be removed from an electricity security index to enhance measurability; and their non-CO_2 emitting share of electricity generation metric appears to duplicate their electricity capacity diversity metric. The former is proposed by the Institute to indicate the extent to which the electricity sector is diversifying into new power sources; the latter assesses the market share of the primary categories of electric power generating capacity, adjusted for availability.

Turing to the Institute's R&D metrics, these are included within their energy security index to indicate the prospects for new scientific and technological breakthroughs via federal or private industry means, and the extent to which suitably qualified personnel will be available to work in energy-specific areas. However, scientific and technological breakthroughs are more likely to occur out-of-state. Hence, one can question the extent to which increased state investment in electricity R&D, or a growth in the availability of suitably qualified graduates, in isolation from other states or nations, will significantly enhance electricity security at a state level.

The key additions relate to environmental stewardship. From an emissions perspective, nitrous oxide (NO_X) should be considered alongside carbon dioxide and sulfur dioxide. The inclusion of numerous greenhouse gases could potentially result in double-counting, as climate change rather than the emissions themselves is the real issue of relevance. However, this needs further reflection and consultation with experts in the field.

A case can also be made for the inclusion for two other metrics over looked by both 2010 energy security indices, provided appropriate data is available and accessible (the M and A of SMART). These are the land resource requirements of conventional and renewable generation sources, and water usage (gallons per MWh by generation source).

4.2. Applying the Electricity Security Metrics to Arizona

Table 8 summarizes the 12 metrics identified within this Section as being of value for a state assessment of electricity-security. 10 of the metrics are drawn, in part or whole, from Sovacool and Brown's or the Institute for 21st Century Energy's indices. Water usage and land resource requirements are two new potential additions. The themes and issues raised by these metrics will now be explored from an Arizona perspective.

Table 8: Summary of Metrics Applicable for a State Assessment of Electricity Security

Availability	**Affordability**
• Diversification of Electricity Sources • Electricity Capacity Margins • Electricity Transmission Line Mileage	• Retail Prices • Electricity Price Volatility
Efficiency	**Environmental Stewardship**
• Electricity Expenditure per GDP • Electricity Consumption per Capita	• SO_2 Emissions • CO_2 Emissions • NO_X Emissions • Land Resource Requirements • Water Usage

Source: Authors

4.2.1. Diversification of Electricity Sources

The flexibility of a state's power sector, and its ability to dispatch electricity from a diverse range of sources, is clearly of relevance. The more varied the sources used to generate electricity, for example, the less susceptible a state should be to short-term outages caused by unavailability of supply or technological breakdown from a single generating method.

Arizona's Renewable Energy Standard (RES) currently mandates impacted utilities such as APS and TEP to source 15% of their energy from renewables by 2025.[18] APS currently generates almost 290 MW of electricity from renewable sources, and has plans to add at least a further 447 MW by 2013, thus illustrating a growing commitment to energy diversification. Of this, 250 MW concentrating solar will be generated at Solano in 2013, supplementing the current 1 MW from Saguaro. A further 102 MW will be generated via solar PV, as listed in Table 9. The plants

[18] Although not mandated to do so, SRP has also adopted an RES-style renewable energy goal.

listed in this table have been designed and constructed by third-party solar developers, contractors and equipment providers. However, APS has provided the finance and will own the plants, thereby demonstrating their commitment to diversify electricity generation sources.

Table 9: APS' Solar PV Generation – Operational and Planned

Location	Total Generating Capacity	Start Date
Cotton Center, Gila Bend	17 MW	November 2011
Luke Air Force Base, Glendale	14 MW	2012/2013
Prescott Airport	3 MW	2002 (Phases completed 2006)
STAR Center and Small Solar, Tempe	1 MW	1985
Hyder	16 MW	Qtr. 4, 2011
Chino Valley	19 MW	Qtr. 4, 2012
APS/Sun Edison, Prescott	10 MW	Fall 2011
Paloma, Gila Bend	17 MW	September 2011
Recurrent Energy Ajo 1, Ajo	5 MW	n/a[19]

Source: APS[20]

Assuming these diversification plans come to fruition, increasing the range of sources used to generate electricity will enhance electricity security within Arizona because:

- The renewable energy sources are predominantly local, thereby reducing the percentage needed to be sourced out-of-state.
- Any temporary shortfall in existing fossil-fuel or nuclear generation will be at least slightly less dramatic if the utilities have diversified into other forms of generation.

4.2.2. Electricity Capacity Margins

The presence of spare capacity within the electricity power system at peak load, as a percentage of total peak capability, is also of relevance for electricity security, as it will enable a state's utilities to better respond to the disruption or temporary loss of some production capacity, meet

[19] APS will receive all the energy generated from this plant through a purchase power agreement.
[20] APS Commitment to Renewable Energy, downloaded from the APS website, April 2011: http://www.aps.com/main/green/choice/interactive-map.html

any short-term fluctuating demand for electricity, and satisfy the needs of a growing population. There are two potential sources for this particular data:

- WECC's 2010 Power Supply Assessment Report, which evaluates generation resource reserve margins in MW for summer (July) and winter (December) peak hours, 2011-2019, using data submitted by WECC member utilities in spring 2010.
- KEMA/ACC's (2010) Sixth Biennial Transmission Assessment, 2010-2019.

Combining Arizona's unused available capacity with New Mexico and Southern Nevada in a Desert South West sub-region, WECC uses PROMOD to calculate the Power Supply Margin (PSM) of a sub region to meet its total load requirements[21] through a combination of local resources and imports from other sub-regions, minus exports. A PSM equal to or greater than zero denotes that the target, including the reserve margin, is met. A PSM less than zero denotes that the sub-region's native generation and calculated imports are less than the target amount.

WECC concludes that the Desert South West sub-region has a positive PSM, 2011-2019, albeit with a higher PSM in winter than summer. However, from a measurement perspective, there are potential problems with this data for an Arizona-specific electricity security metric. First, it is not exclusively for Arizona, additionally encompassing New Mexico and Southern Nevada. Second, and perhaps more importantly, it is difficult to draw a conclusion about the impact of renewables upon electricity capacity margin, because each class contains renewable and non-renewable changes, with the net capacity gains from all classes greater for non-renewables (1225 MW in summer; 1350 MW in winter) than renewables (510 MW in summer; 230 MW in winter).

An alternative report addressing electricity capacity margin is KEMA/ACC's (2010) Sixth Biennial Transmission Assessment, 2010-2019. Using reliability must run (RMR) studies, this concludes that the Phoenix, Tucson and Yuma areas have "… sufficient maximum load serving capability to reliably serve the respective area's load during the next ten year period" (p.85). KEMA identifies a potential problem for Santa Cruz County in 2010, but not for 2013 or 2019; Mohave County has no RMR requirement. This report also concludes:

[21] This is defined as demand plus a target reserve margin.

- The estimated in-state generation capacity of 33,000 MW in 2019 is 11,000 MW higher than required to serve Arizona's statewide demand forecast of 22,000 MW.
- Bi-directional transfer capability between Arizona and neighboring states in aggregate is over 12,000 MW, thereby representing "… a significant transmission capacity available for wholesale transactions" (p.88).

These latter calculations assume a greater commitment to renewable energy resources in line with Arizona's RES, although the level of detail provided is somewhat sketchy.

It is difficult, therefore, to make any definitive conclusions about the impact of Arizona's solar installations upon electricity capacity margins, as the pertinent numerical measure is unclear. WECC's 2010 Power Supply Assessment Report scope is significantly wider than Arizona, making it difficult to draw conclusions about the impact of renewables upon electricity capacity margins within the state. KEMA/ACC's (2010) Sixth Biennial Transmission Assessment, 2010-2019, despite suggesting that the key conurbations within Arizona have sufficient maximum load serving capability to reliably serve load during the next ten years, including current RES targets, provides little detail from a renewables perspective.

4.2.3. Electricity Transmission Line Mileage

The literature suggests that electricity transmission line mileage is of relevance for electricity security to the extent that continued investment within the infrastructure will enable utilities to limit outages and reliably meet demand.

KEMA/ACC (2010) refers to a $15 billion commitment in capital infrastructure expansion within the Western Connect (2010-2019), including 1,573 miles of planned lines above 100 kV in Arizona. This includes 11 new projects of voltage class 115 kV to 500 kV during 2010-2019, and 12 new projects post-2019, filed as part of the Sixth Biennial Transmission Assessment, cumulatively accounting for approximately 466 miles (p.10). However, KEMA's report also concludes:

- It will take Arizona four years longer to reach the level of demand previously forecast for the period 2010-2019 due to current economic conditions, potentially enabling the delay of at least some planned reliability-driven transmission projects.
- Utility-scale renewable generation in line with the state's renewable energy standard will almost certainly require "… at least some transmission improvements that are different from those that would be otherwise needed" (p.46), with renewables accounting for 17% to 29% of the system peak load by 2025.

This latter point suggests that a greater emphasis upon renewables, such as solar, could have repercussions for the state's electricity security, if new types of transmission improvement are not forthcoming. At the same time, APS' current preference for the creation of multiple 20 MW or less solar installations, rather than one large solar installation, suggests a potentially positive impact from a security perspective, given that the failure of any smaller plants should in theory exert less of a negative impact upon reliability than the failure of a bigger plant.

4.2.4. Retail Price

Retail price is of relevance for electricity security to indicate the availability of low-cost power. Higher prices represent a potential barrier to end-user purchase, thereby undermining access to affordable, reliable power supply and, by corollary, negatively impacting electricity security. Between 1990 and 2009 in Arizona, EIA (2011d)'s Electric Power Annual 2009[22] states that:

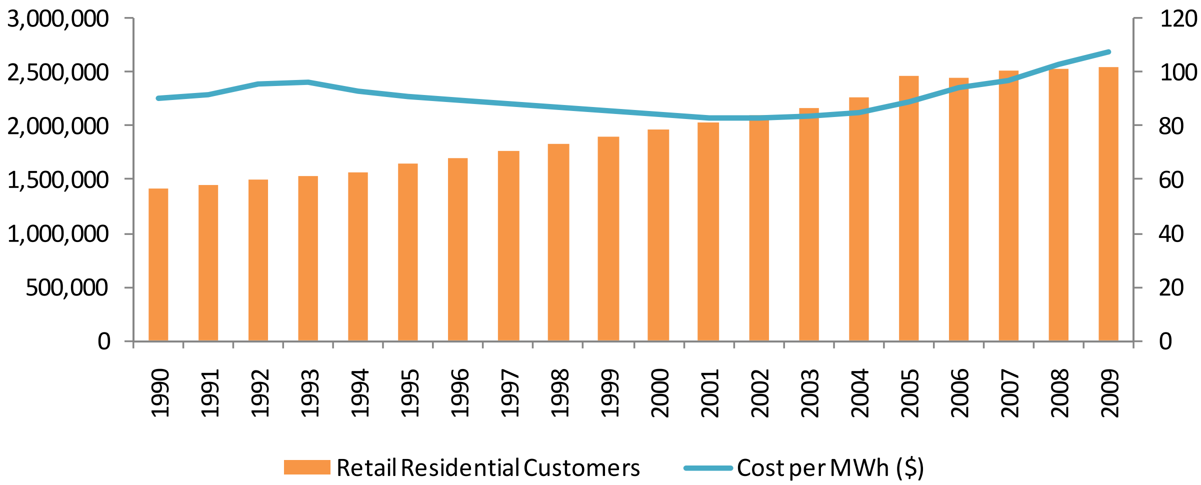
- The total number of retail residential customers grew by 79%.
- Total retail residential sales, in megawatt hours, grew by 213%.
- Total retail residential revenue grew by 254%.

Figure 2 plots annual fluctuations in the retail residential cost per MWh against the total number of residential customers in Arizona. This shows that the absolute cost per MWh fell between 1993 and 2002, and did not rise above the 1993 rate of $96.46 until 2007. It then continued to increase by a further $11 during the following two years. However, from 1990 to

[22] This is the latest data available, released in November 2010 and downloaded in April 2011 from: http://www.eia.doe.gov/cneaf/electricity/epa/epa_sprdshts.html

2005, the total number of retail residential customers also rose each year, which superficially suggests that the number of customers in Arizona might not be a key determinant of retail residential price.

Figure 2: Cost per MWh ($) and Number of AZ Retail Residential Customers, 1990-2009



Source: EIA (2010a, 2011d)

Average sales revenue per residential customer has increased sharply since 2004 in absolute terms, but since 2005 in chained 2005 dollars, thereby exerting a negative influence upon electricity security, as illustrated in Table 10.

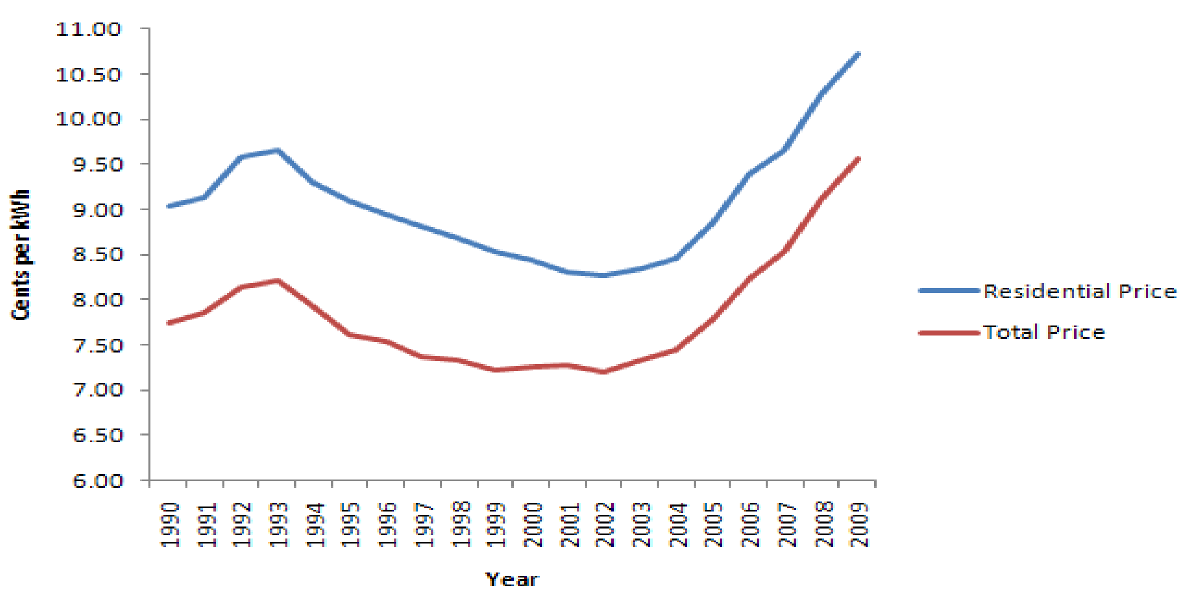
Figure 3 also illustrates a recent upward trend in absolute cost for electricity within the state, comparing the annual residential and total price for Arizona's total electric industry since 1990, expressed in cents per kilowatt-hour.

Table 10: Average Electricity Sales per Arizona Residential Customer

Year	Total Retail Residential Revenue ($)	Total Retail Residential Revenue (2005 $)	Total Retail Residential Customers	Average Revenue per Residential Customer ($)	Average Revenue per Residential Customer (2005 $)
1997	1,824,014,000	2,017,936,254	1,768,748	$1,031.25	$1,140.88
1998	1,874,879,000	2,086,623,801	1,830,062	$1,024.49	$1,140.19
1999	1,921,783,000	2,139,564,227	1,896,943	$1,013.09	$1,127.90
2000	2,096,081,000	2,320,822,478	1,959,669	$1,069.61	$1,184.29
2001	2,174,365,000	2,376,310,295	2,032,358	$1,069.87	$1,169.24
2002	2,184,700,000	2,348,553,116	2,095,776	$1,042.43	$1,120.61
2003	2,315,709,000	2,450,031,606	2,165,899	$1,069.17	$1,131.18
2004	2,446,631,000	2,523,207,110	2,255,973	$1,084.51	$1,118.46
2005	2,707,355,000	2,707,355,000	2,460,694	$1,100.24	$1,100.24
2006	3,041,748,000	2,945,333,619	2,442,903	$1,245.14	$1,205.67
2007	3,327,590,000	3,133,301,490	2,513,923	$1,323.66	$1,246.38
2008	3,412,297,000	3,152,438,091	2,528,405	$1,349.58	$1,246.81
2009	3,524,074,000	3,201,691,386	2,544,383	$1,385.04	$1,258.34

Source: EIA (2010a, 2011d)

Figure 3: Arizona's Annual Electricity Price (Cents per kWh)



Source: EIA (2010a, 2011d)

Renewable utility-scale electricity generation technologies such as solar are usually perceived to be more expensive than conventional generation sources due to higher technology costs, intermittency and storage issues, amongst other things. To measure the overall competitiveness of different generating technologies, energy analysts and economists therefore use levelized cost. This represents the present value of the total cost of building and operating a generating plant over an assumed financial life and duty cycle, converted to equal annual payments, and expressed in real dollars to remove the impact of inflation. Levelized cost therefore reflects overnight capital cost, fuel cost, fixed and variable O&M cost, financing costs, and an assumed utilization rate for each plant type. These are all purely financial considerations. No attention is paid to environmental costs. Renewables today are generally perceived to be more expensive without environmental costs included.

Table 11 estimates the levelized cost of new electricity generation technologies in 2016. This suggests that the inclusion of renewables within the electricity generation mix will have, at least in the short term, a negative impact upon retail residential electricity prices, and therefore exert a negative influence upon electricity security. The EIA (2011d) also suggests that a lag of 1-2 years can take occur between changes in fuel prices and electricity power prices, as changes in retail electricity rates are dependent upon a state's utility regulatory review process.

In the longer term, Perez, Zweibel and Hoff (2011) argue that solar energy production will enjoy a price advantage over fossil fuels used for electricity generation, based upon an assumption that fossil fuel costs will rise exponentially, due to dwindling supply and accelerating demand from new economies. If this happens, then an increase in solar generating sources could exert some positive influence upon electricity security. However, in the short to medium term, a greater use of solar will in all likelihood increase retail prices and, therefore, represent a negative influence upon electricity security.

Table 11: Estimated Levelized Cost of Electricity Generation Technologies in 2016

	Capacity Factor (%)	U.S. Average Levelized Costs (2009$ / megawatt hour) for Plants Entering Service in 2016				
		Levelized Capitalized Cost	Fixed O&M	Variable O&M (including fuel)	Transmission Investment	Total System Levelized Cost
Conventional Coal	85	65.5	3.9	24.5	1.2	95.1
Advanced Coal	85	74.7	7.9	25.9	1.2	109.7
Advanced Coal CCS	85	92.9	9.2	33.3	1.2	136.5
Natural Gas Conventional Combined Cycle	87	17.5	1.9	44.6	1.2	65.1
Natural Gas Advanced Combined Cycle	87	17.9	1.9	41.2	1.2	62.2
Natural Gas Advanced Combined Cycle with CCS	87	34.7	3.9	48.6	1.2	88.4
Natural Gas Conventional Combustion Turbine	30	45.8	3.7	69.9	3.5	123.0
Natural Gas Advanced Combustion Turbine	30	31.7	5.5	61.3	3.5	102.1
Advanced Nuclear	90	90.2	11.1	11.7	1.0	114.0
Wind	34	83.3	9.5	0.0	3.4	96.1
Wind Offshore	34	209.7	28.1	0.0	5.9	243.7
Solar PV	25	194.9	12.1	0.0	4.0	211.0
Solar Thermal	18	259.8	46.6	0.0	5.8	312.2
Geothermal	91	77.4	11.9	9.5	1.0	99.8
Biomass	83	55.4	13.7	42.3	1.3	112.6
Hydro	53	78.5	4.0	6.2	1.8	90.5

Source: EIA (2011b)[23]

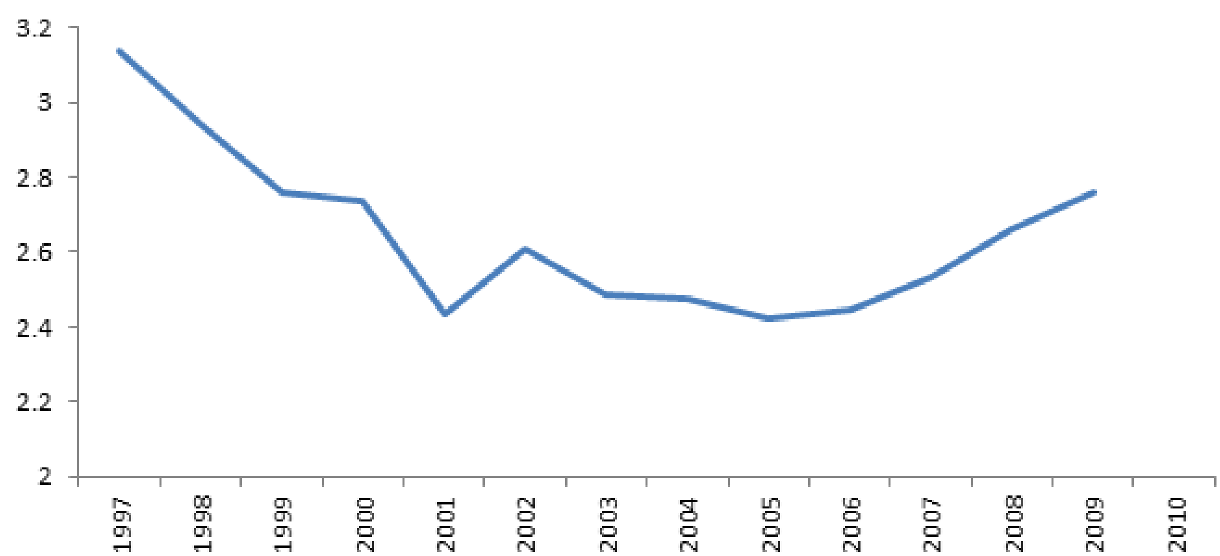
[23] See: http://www.eia.gov/forecasts/aeo/electricity_generation.cfm

4.2.5. Electricity Price Volatility

Power price hikes also affect economic activity – hence the inclusion of energy expenditure per $1,000 of GDP to indicate the magnitude of energy costs in the economy and its susceptibility to energy price volatility. Goto and Karolyi (2003) suggest that electricity price volatility is related to seasonality and other supply and demand forces.

Figure 4 plots total electricity sales (all sectors) against Arizona's GDP, 1997-2009, in chained 2005 dollars. This suggests that the years 2000-2002 were relatively volatile for electricity prices, expressed as a percentage of state GDP, for the Arizonan economy. However, it does not identify any marked swings in price changes during other years. Total electricity sales accounted for a declining percentage of state GDP in real terms at the turn of the century, and a larger, growing percentage of state GDP since 2005 – the latter echoing a trend identified within Table 10 for average electricity sales revenue per residential customer. This is perhaps a reflection of the hedging agreements secured by the state's utilities for coal and natural gas, the insignificance of petroleum for electricity generation, and the high availability of coal for electric power generation within Arizona which has kept electricity prices below the national average.

Figure 4: Total Electricity Sales (All Sectors) as a Percentage of AZ GDP (chained 2005 $)



Sources: EIA (2010a, 2011d) and U.S. Bureau Economic Analysis

Table 12 illustrates the average cost of coal for Arizona's total electric power sector, 2000-2009, compared to the national average and neighboring states. Arizona's emphasis upon coal for electricity generation has therefore tended to temper end-use electricity prices.

Table 12: Average Annual Price of Coal for AZ Electric Power Sector ($ per million Btu)

State	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Arizona	**$1.2**	**$1.2**	**$1.2**	**$1.3**	**$1.3**	**$1.4**	**$1.4**	**$1.6**	**$1.7**	**$1.8**
California	$1.4	$1.1	$1.9	$1.8	$1.9	$1.4	$1.7	$1.9	$2.2	$2.2
New Mexico	$1.4	$1.5	$1.5	$1.4	$1.5	$1.5	$1.6	$1.8	$2.0	$1.9
Nevada	$1.3	$1.3	$1.3	$1.4	$1.4	$1.5	$1.7	$1.9	$2.2	$2.2
U.S. Average	***$1.2***	***$1.2***	***$1.3***	***$1.3***	***$1.4***	***$1.5***	***$1.7***	***$1.8***	***$2.1***	***$2.2***

Source: EIA (2011a)

Increasing the amount of solar used to generate electricity in-state could increase the annual volatility of electricity prices if historical weather patterns are ignored, and greater emphasis is devoted to petroleum as the back-up generation fuel. FERC (2011), for example, attributed significant swings in the price of wholesale electricity across the U.S. in 2009 and 2010 to increases in fuel prices, weather patterns and higher power loads requiring higher cost generators. However, Arizona's utilities are highly unlikely to overlook historical weather patterns, or use petroleum as a back-up generation fuel. The most likely back-up generation fuel is natural gas, which could also apply an upward pressure on electricity prices.

As a result, incorporating more solar into Arizona's electricity generation mix could have some negative impact upon electricity security from a price volatility perspective, at the very least until solar power storage issues are resolved.

4.2.6. Electricity Consumption per Capita

Electricity consumption per capita measures the million Btu of electricity consumed per person per year within the state. Electricity security will benefit the lower the electricity consumption per person per year, as this will result in less power demands being placed upon the utilities.

In 2009, Arizona's residential sector consumed 45% of total state electricity, compared to 40% by the commercial sector and 15% by the industrial sector. This sectoral split differs to the U.S., where the residential and commercial sectors, on average, consume 38% and 36% of total electricity, and the industrial sector 26%. Table 13 compares the electricity consumption per capita for Arizona in 2009 with contiguous states and the national average.

Table 13: Electricity Consumption per Capita, 2009

	Population	Total Electricity Consumption (Million Btu)	Million Btu per Capita
Arizona	6,595,778	250,563,796	37.99
California	36,961,664	885,737,373	23.96
Colorado	5,024,748	174,142,060	34.66
Nevada	2,643,085	116,981,864	44.26
New Mexico	2,009,671	73,862,630	36.75
Utah	2,784,572	94,130,751	33.80
United States	***307,006,550***	***12,273,012,804***	***39.98***

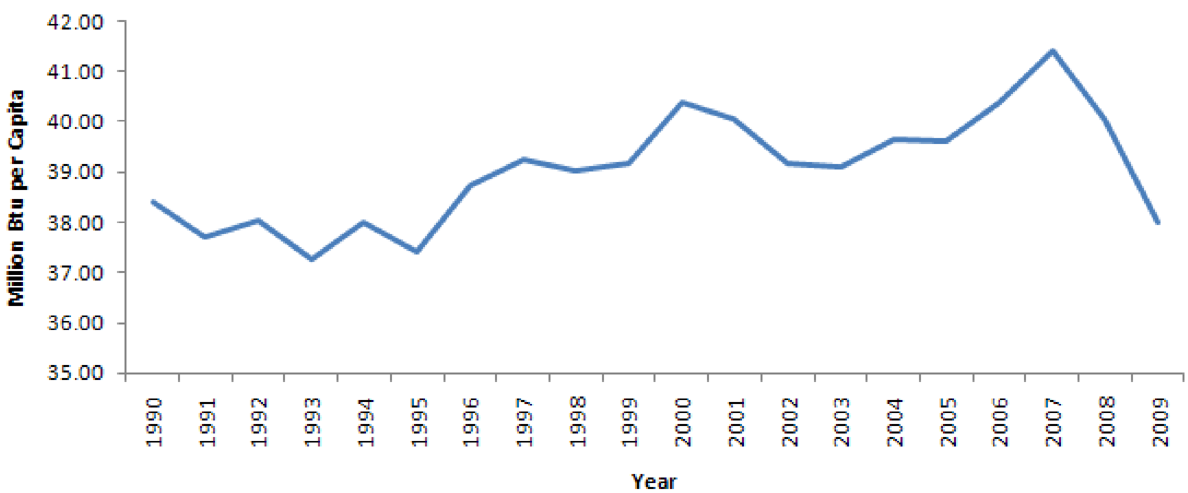
Sources: U.S. Census, EIA (2010a, 2011d)

This suggests that Arizona is below the national average of 39.98 million Btu per capita. However, Arizona's consumption of 37.99 million Btu per capita is greater than all neighboring states apart from Nevada. This is possibly in part a reflection of Arizona's greater demand for air conditioning within homes. The EIA has also estimated that more than one-half of Arizona households also rely on electricity as their main energy source for space heating.

Figure 5 illustrates the electricity consumption trend per capita for Arizona, 1990-2009. The 2009 figure of 37.99 million Btu per capita is the lowest level of electricity consumption since 1995. The two year fall since 2007 is in all probability linked with the economic recession.

It is difficult to predict the impact of any increase in electricity generation from solar upon the electricity consumption per capita metric. EIA projections for energy as a whole, for example, forecast a continuing gradual reduction throughout the U.S., driven by a combination of high energy prices, policy changes and energy efficiency requirements (Institute for 21st Century Energy 2010(b), p.25). This does not mean that the metric should be excluded from electricity security, as a baseline forecast for the composite index will be needed going forward. However, ambiguous results are not consistent with the SMART's framework for metric/index development.

Figure 5: Electricity Consumption Per Capita in Arizona, 1990-2005 (Million Btu)



Sources: U.S. Department of Energy (2008), EIA (2010a, 2011d) and U.S. Census

4.2.7. Electricity Expenditure per GDP

Electricity expenditure per GDP assesses the importance of electricity as a component of a state's economic growth. The lower the amount of Btu needed to produce $1 of real GDP, the less the demands placed upon utilities, and greater the degree of electricity security. Table 14 compares Arizona's electricity intensity in 2009 with contiguous states and the national average. This suggests that Arizona is above the national average of 875.71 Btu per 2009 dollar of GDP. Arizona's 1003.42 Btu per 2009 dollar of GDP is also greater than all neighboring states.

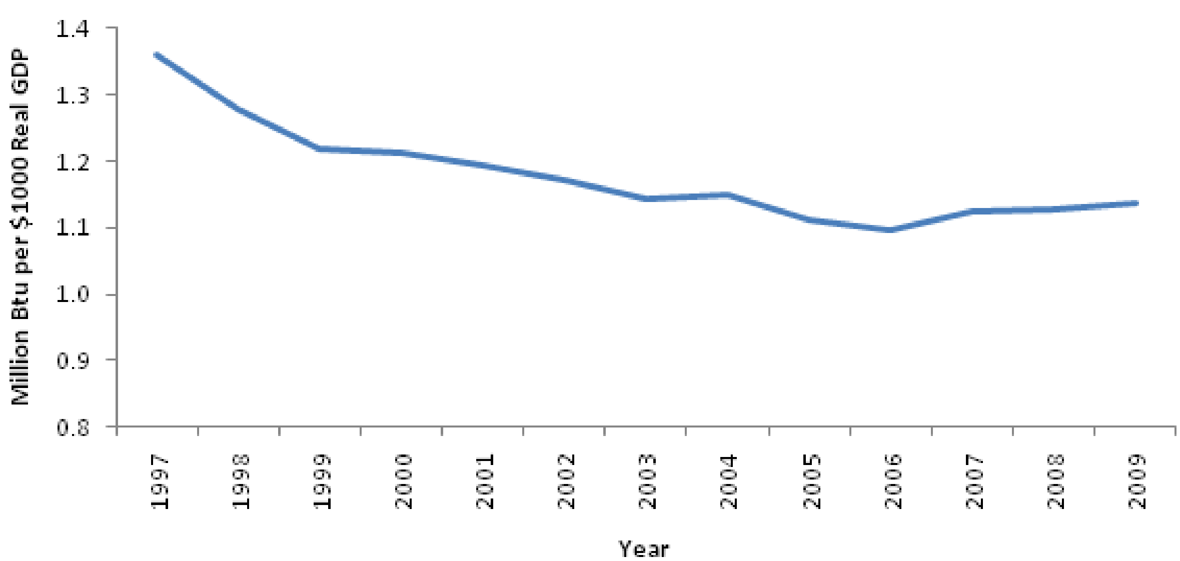
Figure 6 illustrates the million Btu of electricity used in the economy per $1,000 of real (2005) GDP since 1997. This suggests that electricity intensity has fallen from 1,311 Btu to produce one dollar of real (2005) GDP in 1997, to 1,085 Btu to produce an equivalent one dollar of real (2005) GDP in 2009 - a reduction of approximately 17% between the two years. However, an annual decline in Arizona's electricity intensity between 1997 and 2006, hitting a low of 1,046 Btu to produce one dollar of real (2005) GDP in 2006, has started to rise once again from 2007 onwards, at 1.074 Btu, 1,077 Btu and 1,085 Btu respectively. Once again, it is difficult to predict the impact of any increase in electricity generation from solar upon the electricity intensity metric.

Table 14: Electricity Intensity, 2009

	GDP (Millions 2009 $)	Total Electricity Consumption (Million Btu)	Btu per 2009 $ GDP
Arizona	$249,711	250,563,796	1,003.42
California	$1,847,048	885,737,373	479.54
Colorado	$250,664	174,142,060	694.72
Nevada	$125,037	116,981,864	935.58
New Mexico	$76,871	73,862,630	960.86
Utah	$111,301	94,130,751	845.73
United States	**$14,014,849**	***12,273,012,804***	***875.71***

Sources: US Bureau Economic Analysis, EIA (2010a, 2011d)

Figure 6: Arizona's Electricity Intensity, 1997-2009



Sources: US Bureau Economic Analysis, EIA(2010)

One possible reason for this difficulty is provided by Huber and Mills (2005), who argue that enormous advancements in efficiency are coupled with an ever growing demand for energy. That is, people at best simply spread their same level of consumption over an ever growing portfolio of appliances, rather than use the efficiencies to reduce their consumption. Croucher (2010) also suggests that air conditioning unit efficiency improvements, for example, will generally decrease the marginal price of using the devices, potentially encouraging owners to lower their thermostats to levels below the energy-efficient intervention, which can result in greater AC electricity consumption. This suggests that efficiency initiatives require better regulations and enforcement, life-cycle costing and key changes in consumer behavior to be effective, as demand will always outpace the saving potential.

Sovacool (2007) acknowledges difficulties in measuring the effectiveness of energy efficiency savings due to double counting of savings, the use of inappropriate discount rates, a failure to define the right baseline, or inability to correct for free riding or the rebound effect. Such a difficulty therefore calls into question the metric's relevance for an assessment of a state's electricity security from a SMART perspective. However, despite the absence of rigorous case studies, Sovacool still concludes:

> "… the historical record suggests that energy efficiency practices represent the most feasible way of cutting electricity demand." (p.103)

4.2.8. CO_2, SO_2 and NO_X Emissions

If the emphasis within the literature upon the importance of environmental issues for energy security is accepted, there is no obvious reason to question the relevance of emission metrics for a state assessment of electricity security. Sovacool and Brown highlight two types of emission for energy security, namely carbon dioxide and sulfur dioxide. The Institute for 21st Century Energy simply argues that the lower the number of Greenhouse Gas emissions reduction mandates, and lower the energy CO_2 emissions, the lower the risk to energy security. Table 15 summarizes the metric ton emissions by energy source for the electric utilities and total electric power industry in 2009 for carbon dioxide, sulfur dioxide and nitrous oxide emissions.

Any move by the electric utilities or power industry within Arizona to replace conventional sources of electricity generation such as coal with renewables like solar will clearly result in lower emissions and therefore an increase in energy security. However, the different capacity factors between energy sources and solar generation's need for some form of back-up supply (typically natural gas) will prevent a 5% switch from coal to solar equating to a 5% fall in total emission levels. For example, Post (2011) argues that studies using New York and California data show the net CO_2 reduction from wind power to be only a third of, rather than equivalent to the CO_2 quantity produced by, the displaced fossil fuel source.

Table 15: AZ Emissions by Energy Source, 2009

	CO_2 (Metric Tons)	SO_2 (Metric Tons)	NO_X (Metric Tons)
Electric Utilities			
Coal	38,666,845	32,561	56,885
Natural Gas	5,576,726	28	1,898
Petroleum	49,203	5	43
Other Biomass	0	0	234
All Sources	*44,292,774*	*32,594*	*59,060*
Total Electric Power Industry			
Coal	39,202,857	32,786	57,684
Natural Gas	14,269,696	73	3,360
Petroleum	51,085	5	51
Other Biomass	0	0	332
Wood and Wood-Derived Fuels	0	19	194
Other	0	0	1
All Sources	*53,523,638*	*32,883*	*61,622*

Source: EIA (2010a, 2011d)

Nevertheless, the US Photovoltaic Industry claims that on a typical annual "per kilowatt" basis, solar PV will offset or save up to 16 kilograms of NO_X, 9 kilograms of SO_X and 0.6 kilograms of other particulates, alongside 600 to 2300 kilograms of CO_2 – the actual savings varying with regional fossil fuel mix and solar insolation. This emissions reduction will have a positive effect on energy/electricity security (NREL, 2001).

4.2.9. Other Environmental Metrics

Land resource requirements and water usage are also important potential environmental concerns for electricity security, although the ease with which appropriate data can be sourced for the former is problematic, thus undermining the 'A' of the SMART mnemonic.

For example, the land footprint of a coal plant can be compared with a solar farm, Nace (2010) suggesting that the 2,100 GWh emanating from a proposed 7,000 acre solar farm in Blythe, CA., could alternatively be met by a coal plant of 640 acres or less. However, this does not take into account the land required to mine the coal; and the U.S. federal government's method for tracking the exact number of acres disturbed by mining is open to abuse. McDonald et al (2009) also conclude that nuclear, coal and geothermal use the least land for energy production, biofuels or biomass use the most land, and solar lies somewhere in-between. However, the compactness of land use for energy production is not correlated with low biodiversity impacts.

Water usage is a little more straightforward to calculate, as shown by the U.S. Department of Energy's (2006) water estimates for thermoelectric power plants in Table 16, which emphasize choice of process as much as plant type as a key determinant.

Table 16: Water Usage of Thermoelectric Power Plants

		Water Intensity (gal/MWh)		
Plant Type	**Process**	**Steam Condensing**		**Other Use**
		Withdrawal	**Consumption**	
Coal/ Biomass/ Waste	Open loop cooling	20,000-50,000	300	30
	Closed loop tower	300-600	300-480	
	Closed loop pond	500-600	480	
	Dry	0	0	
Nuclear	Open loop cooling	25,000-60,000	400	30
	Closed loop tower	500-1,100	40-720	
	Closed loop pond	800-1,100	720	
	Dry	0	0	
Geothermal Steam	Closed loop tower	2,000	1,400	n/a
Solar Trough	Closed loop tower	760-920	760-920	8
Solar Tower	Closed loop tower	750	750	8
Natural Gas Combined Cycle	Open loop cooling	7,500-20,000	100	7-10
	Closed loop tower	230	180	
	Dry	0	0	
Coal Integrated Gasification Combined Cycle	Closed loop tower	250	200	7-10 and 130 (process water)

Source: U.S. Department of Energy (2006)

5. Monetizing Electricity Security

The preceding Section's attempt to apply a potential range of metrics to Arizona, primarily drawn from Sovacool and Brown or the Institute for 21st Century Energy's energy security indices, illustrates at least two difficulties:

- It is not always possible to source relevant, quantifiable data, with clearly defined inputs and outputs for an electricity security metric.
- Even when appropriate data can be found, the results sometimes fail to offer meaningful insight for a state's level of electricity security.

The resolution of these difficulties is imperative if the proposed metrics are to satisfy the rigors of the SMART framework and accurately assess Arizona's electricity security as a composite index.

However, assuming that the sourcing and interpretative problems highlighted can ultimately be rectified (and it is not clear whether this is possible), how can the proposed 12 metrics be combined into a composite, numerical index? The simplistic aggregate scoring and inherent subjectivity of the indices developed by Sovacool and Brown, and the Institute for 21st Century Energy, have already been questioned in Section 3.3; and the numeric measure for the 12 metrics is not clear. Perhaps, then, a new approach is needed to develop a quantitative index or measure of electricity security at a state level.

One possible solution is to monetize electricity security, and reposition the 12 metrics discussed in Section 4.2 as either specific types of risk, or mitigating factors. This would acknowledge the relevance of many issues highlighted by the 12 metrics, but present them within a common framework that allows for a numeric, aggregate measurement of a state's electricity security.

Table 17 draws primarily from the 12 metrics discussed in Section 4.2 to illustrate key risks and mitigating factors for electricity security in Arizona. This table suggests five broad categories of risk – pricing, system/infrastructure, raw fuel supply, environmental and end-user.

Table 17: Risk Factors & Mitigations for Electricity Security in Arizona

RISK TYPE	RISK	RISK DESCRIPTION	MITIGATIONS
PRICING	Price Volatility	Susceptibility of end-users and the local economy to price shocks and changes	• Diversify/change generation mix sources • Energy efficiency
	Price Rises	Increase in utility prices to supply electricity to residential, commercial and industrial end-users.	• Diversify/change generation mix sources • Energy efficiency
	Government Regulations	Government regulations such as the introduction of a carbon tax	• Diversify/change generation mix sources • Energy efficiency • Encourage small-scale distributed generation
SYSTEM	Transmission Grid Failure	Temporary breakdown in the supply of power to end-users, caused by technological failure, vandalism, terrorism, or natural disasters and events (e.g. weather)	• Invest in transmission infrastructure • Increase spare capacity at peak load • Use spy satellites to monitor long stretches of power lines • Encourage small-scale distributed generation
	Power Plant Failure	Temporary breakdown in the supply of power to end-users, caused by natural events, technological failure, vandalism, terrorism, etc.	• Invest in power plants • Encourage small-scale distributed generation • Energy efficiency
	Capacity Overload	Insufficient spare capacity to meet end-user demand	• Energy efficiency measures • Increase spare capacity at peak load • Increase reliance on local generation mix sources
	Government Regulations	Regulatory constraint of electricity production – e.g. limiting prices or for environmental reasons	• Diversify/change generation mix sources • Energy efficiency • Encourage small-scale distributed generation

Table 17 (Continued): Risk Factors & Mitigations for Electricity Security in Arizona

RISK TYPE	RISK	RISK DESCRIPTION	MITIGATIONS
FUEL SUPPLY	External Fuel Supplier Dependency	Degree of reliance on out-of-state fuels for electricity generation mix	• Hedging or long-term agreements • Diversify generation mix sources • Increase reliance on local generation mix sources
	Intermittency	Renewable generation supply interruptions caused by weather, etc.	• Diversify/change generation mix sources • Secure back-up generation • Technological advances
	Competition for Energy	Increased competition (national and international) for raw fuels to generate electricity	• Hedging or long-term agreements • Diversify generation mix sources • Increase reliance on local generation mix sources
ENVIRONMENTAL	Water	Availability of water for electricity generation technologies	• Diversify/change generation mix sources • Recycle 'used' water • Encourage small-scale distributed generation
	Emission Levels	Environmental impact of electricity generation technologies	• Diversify/change generation mix sources • Technological advances • Energy efficiency • Encourage small-scale renewables distributed generation
END-USER	Power Demand Increases	Increases in end-user demand on grid (temporary or long-term)	• Energy efficiency measures • Increase spare capacity at peak load • Increase reliance on local generation mix sources

Two pricing risks identified in this table echo key metrics in the 2010 energy security indices - price volatility and price rises. Government regulations, such as the introduction of a carbon tax, are also an exposure risk for pricing. Potential mitigations for pricing risks include the diversification of, or changes to, generation mix sources, and energy efficiency measures.

System/infrastructure risks encompass threats or issues with the equipment used to generate or transmit electricity, and supply it to end-users. They include transmission grid or power plant failure, capacity overload and government regulations. Infrastructure investments, increasing spare capacity at peak load, encouraging small-scale distributed generation, adding more renewables to the generation mix, and energy efficiency measures are all potential mitigations.

Raw fuel supply risks refer to issues affecting the availability of generation mix fuels. They include dependency on external fuel suppliers, intermittency and the risk of increased competition for the raw fuels, nationally and internationally. The mitigations proposed are hedging or long-term agreements, investing in back-up generation, technological advances, the diversification of generation mix sources, and increased reliance on local generation mix fuels. Two additional raw fuel supply risks of potential relevance to a state but not applicable to Arizona are the depletion of local fossil fuel, or renewable energy, resources. The U.S. as a whole has approximately a 300-year supply of coal, if it continues to use it at current rates (American Coal Foundation, 2010); and Section 4.2.5 has already concluded that the high availability of coal for electric power generation within Arizona has contributed to the lower than national average electricity retail prices in the state. Similarly, Arizona benefits from the highest insolation rate in the country. As a result, Arizona's principal native fossil fuel resource (coal) and most abundant renewable resource (solar) will not be threatened with depletion for many years.

Environmental risks for Arizona's electricity security refer to sustainable issues that could impact upon the ways in which electricity is generated, such as emission levels and water usage. The mitigating factors are diversification of the generation mix, the encouragement of small-scale distributed generation, technological advances, and energy efficiency measures.

End-User risk primarily refers to unexpected changes in customer demands for power, on a temporary or longer-term basis. The mitigations proposed for this risk include energy efficiency measures, increased reliance on local generation fuels, and increasing spare capacity at peak load.

To understand the value of this monetization strategy, consider the security implications of an electricity price rise caused by rising coal prices, with reference to the 2009 Arizona electricity generation mix. Table 18 illustrates the percentage of the generation mix for the total electric industry in Arizona in 2009 by fuel source and cost.

Table 18: Arizona's Total Electric Industry Net Generation, 2009

FUEL TYPE	NET GENERATION (MWh)	PERCENTAGE GENERATION MIX	POWER SECTOR CONSUMPTION (Trillion BTU)	DIRECT FUEL COST (Million Dollars)	COST PER TRILLION Btu (Million Dollars)
Coal	39,706,817	35.46%	404.5	731.8	1.809
Natural Gas	34,739,170	31.03%	267.7	1089.5	4.070
Nuclear	30,661,851	27.38%	320.7	190	0.592
Hydroelectric Conventional	6,427,345	5.74%	62.7	*	
Petroleum	62,699	0.06%	0.6	8.9	14.833
Solar Thermal/PV	14,145	0.01%	0.1	*	0
Other	359,223	0.32%	2	8.9	4.450

Source: EIA (2011a, 2011d)

Key: * There are no direct fuel costs for hydroelectric or solar thermal/PV

If the direct cost of coal for generation paid by the total electric industry in Arizona rose by 5% in 2010, and all other prices remained equal, the total fuel costs paid by the industry would increase by 1.8% from $2,029 million to $2,066 million, impacting negatively on retail price and therefore electricity security. However, if the electric industry as a whole increased net generation of solar thermal/PV by 2.5% at the sole expense of coal, ceteris paribus, their 2010 direct fuel costs would be $2,046 million – that is, a 0.9% increase on the previous year, as opposed to the base case rise of 1.8%, due to changes to the generation mix. As a result, the impact of direct fuel costs on retail price would be lower, limiting any negative impact on electricity security.

In reality, there will be a number of conflicting risks and mitigations simultaneously impacting upon electricity security within Arizona. Nevertheless, this simple monetization approach can be adapted to take into account multiple mitigations for one risk, or even multiple risks.

Consider, for example, Table 19, which builds upon the previous example by additionally considering the mitigating effect of energy efficiency improvements on pricing. In 2009, Arizona consumed 37.99 MBtu per capita. However, if a 1% fall in energy consumption per capita in 2010, equally distributed at the same percentage rate across all electricity generation fuels, coincided with a 5% direct increase in the cost of coal and a 2.5% switch from coal to solar generation, the total generation fuel costs paid by the electric industry would fall to $2,026 million - that is, $3 million lower than the previous year and $40 million lower than the delta. The combination of a change to the composition of the generation mix with the energy efficiency improvements would counteract the negative rise in the cost of coal, and thus exert a positive influence on both retail price and electricity security.

Table 19: Electricity Security – Monetization Matrix

ELECTRICITY SECURITY RISK	EXPOSURE	MITIGATIONS	COST
Price Rise	5% increase in the direct cost of coal	• 1% less MBtu consumed per capita • 2.5% switch from coal-generated electricity consumption to solar thermal/PV	• Delta is 2% less than the 2010 base case of $2,066 million • Total raw fuel costs fall, year-on-year, by 0.15%

Although the pricing risks clearly lend themselves to monetization, other risks, such as water or emission levels, at face value do not appear so easy to monetize. However, the electricity security analysis needs to focus upon the monetary implications of the mitigations, rather than the risks themselves, and compare the latter scenarios with the anticipated cost of electricity if the exposure or risks took place without the mitigations. For example, the cost implications of introducing closed loop processes in place of open loop generation processes for water; or the cost of replacing a percentage of fossil fuel generation with renewables generation to reduce emission levels.

The pursuit of a monetization approach, then, enables an objective, numerical assessment of electricity security within a state to occur, analyzing a variety of risks and mitigations within a common, easily accessible and interpretable framework.

Subject to further testing and appropriate data collection, this numerical measure of electricity security could therefore be included within the Az SMART utility-scale tool, to offer additional insight into the impact of new solar installations in Arizona.

6. Conclusion and Recommendations

This paper has attempted to develop a numerical means of assessing electricity security at a state level via the use of a monetization framework for relevant risks and mitigations.

Initially reviewing the energy security literature as a stepping stone to the development of a numerical assessment, the paper has traced the development of energy security from a rather narrow focus upon the import of oil to something far more wide-ranging that touches upon the self-sufficiency, reliability, affordability and sustainability of energy supply.

A critique of two contemporary attempts to quantitatively measure energy security by Sovacool and Brown, and the Institute for 21st Century Energy, has identified many shortcomings, including:

- Data discrepancies and/or the use of subjective measures such as the index of democracy and civil liberties.
- The arbitrary assignment of weighting to groups or categories of metric in either index.
- An inherent duplication of metrics, particularly within the Institute's index.
- Crude scoring techniques.
- The omission of key diversification and emission metrics within Sovacool and Brown's index.
- The Institute's emphasis upon measuring what historically happened, rather than the degree of risk at a particular time to energy security.

Nevertheless, an attempt has been made to utilize 10 metrics from these two energy security indexes for electricity security at a state level:

- Diversification of Electricity Sources
- Electricity Capacity Margins
- Electricity Transmission Line Mileage
- Retail Residential Prices
- Electricity Price Volatility
- Electricity Intensity
- Electricity Consumption per Capita
- SO_2 emissions
- CO_2 emissions
- NO_X emissions

Supplementing these 10 metrics with two additional environmental issues (water usage and land resource requirements), this paper has examined the relevance and consequences of each metric for Arizona's electricity security, if more solar is added to the generation mix, with reference to the SMART framework for goal-setting and objectives.

This Arizona-specific examination has illustrated how the flexibility of the state's power sector, and its ability to dispatch electricity from a diverse range of sources, will affect electricity security, as any temporary shortfall in existing fossil-fuel or nuclear generation will be less dramatic if the utilities have diversified into other forms of generation; and the localized nature of renewables will reduce the percentage of generating fuels needed to be sourced out-of-state.

This paper has also illustrated how any move by Arizona's electric utilities to replace conventional fossil fuel sources of electricity generation with solar will result in lower emissions, although this net reduction will not be equivalent to the CO_2 quantity produced by the displaced fossil fuel source.

More solar within the generation mix has been described as a potentially positive influence upon electricity security from a transmission perspective, if APS' preference for smaller plants is adopted as the principal modus operandi, thereby minimizing the impact of plant failure.

However, KEMA/ACC's call for renewable generation-specific transmission line improvements has been described as a possible negative influence upon energy security, if such plans fail to come to fruition; and the higher technology costs, intermittency and storage issues for solar have been described as sources for end-user price increases, at least in the short-term.

Price volatility concerns have also been described as a potential consequence of a utility's commitment to use more natural gas as a back-up to solar generation, based upon the cost experiences of other states.

All of these conclusions are interesting from an electricity security perspective. However, this paper has also argued that any electricity security measure based upon the 12 metrics will in all probability fail as:

- It is not always possible to source relevant, quantifiable data, with clearly defined inputs and outputs for an electricity security metric.
- Even when appropriate data can be found, the results sometimes fail to offer meaningful insight for a state's level of electricity security.

Rather than follow Sovacool and Brown, or the Institute for 21st Century Energy, and try to mold the 12 metrics into a composite, numerical index, this paper has therefore recommended a new approach for a state assessment of electricity security based upon monetization. This new approach has repositioned the issues and insights raised by the 12 metrics as either electricity security risks or mitigations, and focused upon monetization to provide a common framework for a quantitative assessment.

Identifying five broad categories of risk - pricing, system/infrastructure, raw fuel supply, environmental and end-user – and an extensive, although not exhaustive, list of mitigations, the paper has demonstrated how monetization can quantitatively assess the impact of multiple mitigations upon a specific risk, such as a rise in the direct cost of coal. The paper has also concluded that there is no reason to suggest that the monetization strategy cannot apply across risks.

This has prompted two closing recommendations:

- Additional examination is required to confirm the appropriateness of the monetization strategy for a state's electricity security.
- Assuming this additional examination yields some positive results, an electricity security measure based around monetization should be incorporated into the current version of the Az SMART utility-scale tool to extend the economic, social and technological insights currently provided.

Drawing from the insights provided by this paper, the next logical step for the Az SMART research team is to collect relevant data needed to operationalize the monetization approach, and arrive at an actual value for the metric, dependent upon the extent to which solar is added to Arizona's electricity generation mix.

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