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Does the Polysemic Nature of Energy Security Make it a 'Wicked' Problem?

Lynne Chester

***Abstract*—**Governments around the world are expending considerable time and resources framing strategies and policies to deliver energy security. The term 'energy security' has quietly slipped into the energy lexicon without any meaningful discourse about its meaning or assumptions. An examination of explicit and inferred definitions finds that the concept is inherently slippery because it is polysemic in nature having multiple dimensions and taking on different specificities depending on the country (or continent), timeframe or energy source to which it is applied. But what does this mean for policymakers? Can traditional policy approaches be used to address the problem of energy security or does its' polysemic qualities mean that it should be treated as a 'wicked' problem? To answer this question, the paper assesses energy security against nine commonly cited characteristics of wicked policy problems and finds strong evidence of 'wickedness'.

***Keywords*—**Energy security, policy making, wicked problems.

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I. Introduction

AS the debate about climate change has intensified, the matter of energy supply security has been eclipsed. Governments around the world have, however, been implementing for some time an array of policies directed at improving energy security. What is meant by the term 'energy security' and are there any implications for policymakers?

The next section of the paper considers the nature of energy security in light of the post World War 2 context in which the term's usage has evolved and the wide range of different energy security definitions, explicit and inferred, increasingly apparent in recent decades. This examination leads to a policy conundrum as to whether the problem of energy security should be addressed with traditional policy approaches or treated as a complex, seemingly intractable 'wicked' policy problem. To shed some light on this issue, the paper discusses nine commonly-cited characteristics of 'wicked' problems and assesses if any are attributable to energy security. A concluding section discusses the implications of the findings.

II. The Nature of Energy Security

The term 'energy security' has become ubiquitous to contemporary discussion about energy issues. The term is most commonly found embedded in discussion framed around a handful of notions which denote unimpeded access or no planned interruptions to fuel sources, not relying on a limited number of fuel sources, not being tied to a particular geographic region for fuel sources, abundant energy resources, an energy supply which can withstand external shocks, and/or some form of energy self-sufficiency.

The term's blithe appearance throughout a wide range of reports and documents issued by government and supranational organisations, and academic discourse, has been rarely accompanied by discussion or explanation of the notions which underpin its meaning. The term has quietly slipped into the energy lexicon and assumed a relatively prominent position without any meaningful discourse about its meaning or assumptions. Yet governments around the world have expended considerable time and resources framing strategies and policies to deliver energy security.

Of the limited definitional discussion that has ensued, it has been more peripheral than centre stage and often, the meaning attributed has been more implicit than explicitly stated. Those definitions that can be deduced, or are readily apparent, fall into one of two categories. The first category has the narrower focus around market supply and energy availability at market price. The second category is far broader taking into account a number of dimensions. The evolution of this definitional dichotomy is evident if first we consider the context in which the term 'energy security' has appeared before proceeding to 'unpack' the available definitions or their apparitions.

A. Energy's Political, Economic and Social Context Post World War 2

Post World War 2 many countries, particularly those comprising the OECD, became strongly reliant on Middle East oil as an energy source. Oil was relatively abundant and cheap until the oil price shocks of the 1970s. This led to a view of energy security as synonymous with the need to reduce dependence on oil consumption [1]. This fossil fuel had become integral to the world's post-war economic growth trajectory particularly through the transport sector.

The global economic crisis of the 1970s led to strident criticism of government intervention and regulation. By the 1980s the need for greater competition and less government involvement was strongly advocated for network sectors (especially electricity, gas and telecommunications) which had been traditionally dominated by government monopolies.

Lynne Chester is Senior Research Fellow at The John Curtin Institute of Public Policy, Curtin University of Technology, Perth, Australia (Corresponding author : +618 9266 1707; fax: +618 9266 3658; e-mail: l.chester@ curtin.edu.au).

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Considerable restructuring of energy markets around the world has subsequently occurred and, in electricity's case, at an astonishing pace [2: 16-26]. Competition has been injected through the breaking up of vertically integrated monopolies, pricing and access regulation of monopoly networks, and the creation of new trading markets. This restructuring has not only been promoted by individual country governments but actively encouraged by the Organisation for Economic Cooperation and Development (OECD), the World Bank, the International Monetary Fund, and international trading agreements such as the General Agreement on Tariffs and Trade (GATT) and the subsequent General Agreement on Trade in Services (GATS).

The late twentieth century emergence of a global market for liquified natural gas (LNG) has not only expanded available fuel sources but also the geographic locations of energy supplies. Concurrently China and India have become major energy importers. More recently, global oil and gas prices have escalated and remained high, compared to their levels in the 1990s. The possibility of serious energy supply interruptions has been heightened with political instability in supplier countries (e.g. oil supplies from Iraq) and the increasing disruption of gas supplies from Russia to Europe given the levels of energy import dependence around the world. Risks to the energy supply chain infrastructure have also come to the fore with the 11 September 2001 terrorist attacks in the United States [3] and natural events such as Hurricane Katrina in 2005 and the 2009 floods and bushfires in north-eastern and south-eastern Australia.

Events such as a rapid escalation in oil prices, disruption of gas supplies to Europe during freezing winter temperatures, electricity blackouts following hurricanes or other severe natural disasters, tend to focus public and media attention on energy supply issues and measures taken by governments to overcome short-term supply disruptions. This also was the focus of energy security strategies following the 1970s oil disruptions. But today's energy supply systems are far more complex than a few decades ago. For example, cross-border pipelines and strategic transport channels feature strongly, China and India have become major energy importers, there is an increasing reliance on an ever-smaller group of oil and gas suppliers, financial markets and energy markets are closely linked, and technology has created interdependencies between electricity and oil refining as well as natural gas processing. Energy markets are exemplars of liberalisation, fossil fuels dominate our growing energy dependence, most countries will never be energy self-sufficient and energy consumption contributes around 80% to global greenhouse gas emissions.

Total world energy consumption is projected to rise by 50% in the 25 year period to 2030 without fundamental policy changes and major supply constraints. Even more rapid growth in greenhouse gas emissions is projected. International organisations have claimed current energy supply and consumption trends are environmentally, economically and socially unsustainable [4].

Energy security is high on the policy agenda of the developed and developing world, and supranational organisations such as the European Commission (EC), World Economic Forum, OECD, North Atlantic Treaty Organisation (NATO), Asia-Pacific Economic Cooperation (APEC) and the G8. The European Union (EU), the United Kingdom and Japan, to name a few, have spent considerable resources developing energy security strategies.

But what is 'energy security'?

B. Definitions of Energy Security

The literature is marked by a very dominant focus on securing supplies of oil and gas (For example, see: [4]-[8]). The literature is also notably marked by 'vapid abstractions' from a "foreign-policy cottage industry that obsesses about the need for nations and their diplomats to worry about and attempt to manage petroleum markets" [9]. Yet the world's most dominant form of energy supply is from electricity making it critical to any country's energy security and warranting attention [10].

Bohi and Toman [11: 1094] state that "energy security can be defined in various ways" although their focus is limited to "economic issues related to the behaviour of markets". Subsequently they define energy insecurity "as the loss of economic welfare that may occur as a result of a change in the price or availability of energy" [12: 1] Some years earlier, the International Energy Agency (IEA) defined energy security as an "adequate supply of energy at a reasonable cost" [13: 29] and later posited that "energy security is simply another way of avoiding market distortions" [14: 23].

This IEA definition of energy security in market terms has been consistently restated and most recently expressed as "energy security always consists of both a physical unavailability component and a price component, [but] the relative importance of these depends on market structure" [15: 32]. A similar approach is mirrored by [16]-[19] and [20: 237] who suggests that the concept is centred on notions of supply 'reliability' and 'adequacy' at 'reasonable' market-determined prices.

The logic which underpins these 'market-centric' definitions goes something like this: as a consequence of the 'liberalisation' of energy markets, energy security [and insecurity] is a market outcome, determined by the operation of the market and thus can only be defined in market terms – particularly supply (physical availability) and price. Continuity of physical supply – often described in terms of availability, reliability, relative shortage or complete disruption – across the total supply chain assumes a singular, unparalleled importance within this definition of the concept.

> A security of supply risk refers to a shortage in energy supply, either a relative shortage, i.e. a mismatch in supply and demand inducing price increases, or a partial or complete disruption of energy supplies [21: 13].

Therefore the purpose of energy security strategies is to overcome "situations when energy markets do not function properly … [and] should be mostly aimed at 'making markets

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work' [22]. Competitive markets and 'independent' regulation are considered the "most effective way of delivering secure and reliable energy supplies" [17: 8]. A corollary of this view comes strongly to the fore in the UK Government's energy approach. The 'right' level of security [i.e. continuity of supply] "depends on the balance between the costs and the benefits of increasing security … [and] is left to the market as suppliers are better placed than Government or the Regulator to understand the value that their different customers place on security of supply" [17: 17).

A further corollary of this market-centric conceptualisation of energy security has been successive endeavours at its 'operationalisation'. The first step was the 'translation' of the market-centric definition into short-term (operational) and long-term (adequacy) threats to supply disruptions based on sources of energy supplies, and subsequent transit, storage and delivery [14], [23]. The second step was quantification of these risks. "To be analytically helpful, a measure of supply security needs to be quantifiable" [24: 2], "can be used as a measure to indicate a desired state" [21: 13] and can "measure risks and policy effectiveness" [25].

Quantitative measurement of 'market-centric' energy security risks has been proceeding since the early part of this decade. Since 2002 the UK Government has published security-of-supply indicators which range across three categories of supply and demand forecasts, market signals (e.g. forward prices for gas and electricity) and market response (planned major new investments). The Clingendael International Energy Programme has developed, in relation to the EU, a Crisis Capability Index (for short-term supply interruption) and a Supply/Demand Index [21][26]. The IEA [15] has also proposed two energy security measurement 'tools' of market power (the price component) and pipe-based import dependence (physical availability). Another example of this quest for quantification has been an extension of the Shannon-Wiener index which is more commonly used to measure biological diversity [27].

Broader definitions of energy security are observable which embrace dimensions other than market supply and market price. For example, the EC's Green Paper *Towards a European strategy for the security of energy supply* stated:

> energy supply security must be geared to ensuring, for the well-being of its citizens and the proper functioning of the economy, the uninterrupted physical *availability* of energy products on the *market*, at a price which is *affordable* for all consumers (private and industrial), while respecting environmental concerns and looking towards *sustainable* development … Security of supply does not seek to maximise energy self-sufficiency or to minimise dependence, but aims to reduce the risks linked to such dependence [28: 1-2, emphasis added).

The hazards posed to each of these dimensions of energy security are identified, by the Green Paper, as physical, economic, social and environmental risks. Moreover, it is recognised that these risks will not be ameliorated or prevented without government intervention - through policy and/or regulatory action – given the complex institutional arrangements which guarantee the existence and functioning of contemporary energy markets.

A similar view is expressed in the European Parliament's response to this Green Paper which highlights notions of adequate capacity to meet demand, and availability through source diversification and many suppliers. The Parliament's response stresses Europe's high oil import dependence, proposes a reduction in transport's demand for oil but contends that dependence on imports of energy fuels "is neither necessarily a bad thing nor economically inefficient provided the sources are diverse, no one supplier is dominant and we can produce sufficient goods and services to pay for them" [29: 17].

The dimensions of availability, affordability, adequate capacity and sustainability are echoed by the Asia Pacific Energy Research Centre [30] and annual issues of the *World Energy Assessment* which defines energy security as "the availability of energy at all times in various forms, in *sufficient quantities* and at *affordable* prices without unacceptable or irreversible impact on the environment" [7: 42, emphasis added]. These latter assessments distinguish between short and long term energy supply interruptions, and stress the need for diversification of local and imported energy sources to keep pace with expected growth in demand [For example: 1]. The APERC's energy security definition of:

> the ability of an economy to guarantee the availability of energy resource supply in a sustainable and timely manner with the energy price being at a level that will not adversely affect the economic performance of the economy [30: 6]

places the concept firmly within the context of the broader economy. It also clearly infers the desirability for government action should economic performance be jeopardised by insufficient, unsustainable and unaffordable market provision of energy.

C. Multiple Aspects of Energy Security

A number of fundamental aspects about the expression 'energy security' are discernible from the discussion thus far. First, an inherent feature of energy security is about the management of risk – the risk of interrupted, unavailable energy supplies; the risk of insufficient capacity to meet demand; the risk of unaffordable energy prices; the risk of reliance on unsustainable sources of energy.

A second point concerns the extent to which the definition of energy security may be framed to reflect a country's (or continent's) energy use 'mix', the abundance of local resources and reliance on imports. This is illustrated by the EC's 2006 Green Paper *A European strategy for sustainable, competitive and secure energy*. The document places a far stronger emphasis on the physical security of supply (network infrastructure, stock, diversification of supplies) than the Green Paper of six years earlier. The objective of supply security, now separated from sustainability, is targeted at "tackling the EU's rising dependence on imported energy" [31: 18] which is projected to rise to around 70% of energy requirements in the next 20 to 30 years. This dependence is to

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be 'tackled' by a number of policy measures such as reducing demand, diversification of the energy mix and supply sources, stimulating investment in adequate capacity, emergency preparedness, and improved energy access for business and citizens. The clear priority of 'energy security' is to minimise the EU's import vulnerability, supply shortfalls and potential supply uncertainty given the high dependence on one single gas supplier [32].

Third, the term 'energy security' clearly reflects a concept and has some form of strategic intent. This view is exemplified by the following definition developed by the Centre for European Policy Studies: "security of supply consists of a variety of *approaches* aimed at insuring against supply risks. Security of supply becomes a cost-effective risk-management strategy of governments, firms and consumers" [33: 3, emphasis added]. The latter point about responsibility or carriage of the strategy is contestable and goes beyond the purposes of the current discussion. The salient point is that energy security is a concept with strategic intent. Energy security is not a policy per se. Specific policy measures are implemented by governments to achieve the objective of energy security, however defined, and these policy measures have increasingly included reliance on competitive markets, the creation of new regulatory regimes to support those markets, and 'geopolitical approaches' [34].

Fourth, the concept of energy security has a temporal dimension. The risks or threats to physical supply differ across short and long term horizons. Short-term risks include extreme weather conditions, accidents, terrorism attacks, or technical failure. The main issue of concern is the *reliability* and *continuity* of available technological and commercial mechanisms which convert primary energy sources for end-use by consumers. Long-term risks concern the adequacy of supply to meet demand and the adequacy of infrastructure to deliver supply to markets which will, in turn, depend on levels of investment and contracting, the development of technology and the availability of primary energy sources [35]. Therefore the meaning attributed to energy security will differ across time because the probability, likelihood and consequences of different risks or threats to supply will vary over time.

A further aspect concerns the differences between energy markets. There are significant differences between the oil, gas, nuclear and electricity energy markets such as the rigidity of transport infrastructure, the difficulties of storage, and the regional nature of markets [14]. Consequently, to apply the concept of energy security to the gas market will result in a different meaning than if applied to the oil market or the electricity market. These security-of-supply differences across energy markets were recognised by the IEA's 1995 gas study. They also are affirmed by the UK Government's decision to develop separate sets of security-of-supply indicators for each energy market.

A final aspect about energy security is possibly the most significant given the implications for the policy role and actions of governments. As we have seen, a definition of energy security may contain both absolute and relative notions. Availability and adequacy of capacity are capable of absolute measurement. Affordability, or the 'reasonableness' of prices, are relative notions with meanings subject to considerable variation. Supra-national organisations, governments, policy advisers and commentators generally favour a definition of energy security narrowly centred on the absolute notions of market supply and market price. Broader definitions, such as those used by the EC, encompass absolute and relative notions. All definitions envisage the market playing a central role in ensuring, enhancing or attaining energy security. However, what is the market paradigm underpinning these definitions?

Two competing market paradigms are evident within contemporary economic thought: the pure Walrasian market which optimally allocates products in a perfectly informed, atomistic world; or the market which is a social, political and historical construct [36]-[37]. Each paradigm defines the interrelationship between market and state, and thus the role to be played by policy to deal with matters such as 'energy security'.

The narrower market-centric definition of energy security clearly is based on the pure Walrasian market with its self-equilibrating properties. Markets are assumed to clear automatically via price adjustments i.e. prices respond to changes in demand or supply, finding equilibrium at the price at which the quantity supplied equals the quantity demanded. These oscillations, according to this paradigm, underpin a systemic stability across markets for all goods and services and ensure an optimal allocation of resources between competing needs. Yet this self-equilibrating nature of the market rests on numerous assumptions such as identical consumers behaving rationally because they are perfectly informed about all the available alternatives, zero transaction costs, no trading at disequilibrium prices, and infinitely rapid velocities of prices and quantities [38: 40-41].

Notwithstanding any perceived incompatibility of these assumptions with economic reality, this paradigm maintains that the market should be left 'unfettered' from state interventions – left pure – to ensure its 'efficient' workings are allowed to determine output and price. The market-centric definition of energy security is couched in these market terms of output (supply) and price and "energy security policies should be mostly aimed at 'making markets work' and letting them work when they do" [22]. This approach strongly advocates a limited role for governments and policy. Energy markets should be allowed to operate 'freely'. Competitively determined output and prices should be the energy security objectives of governments. Adequacy of capacity, affordability and sustainability will be by-products of an 'unfettered' market but the sacrosanct objectives of competitive output and prices will be jeopardised if governments intervene in the pursuit of lower-order objectives.

Not surprisingly, a different view is held by the alternative market paradigm which situates the market as one of a multiplicity of formal and informal institutions comprising

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capitalism. "All institutions, including the market … are defined in relation to the structure of the rights and obligations of the relevant actors" [36: 7] which in the case of the market includes the institutional arrangements that determine and/or regulate market participants, and the objects and process of market exchange. As these 'rights and obligations' are deemed to be the result of politics, the market – like all institutions – is considered to be a political construct. Property rights, and the entitlements bestowed on market participants are not free of politics, nor are the determination of interest rates and wages which impact on every sector of the economy, along with numerous state actions to 'protect' market participants. Far from being 'natural', "markets are the fruit of complex social and historical developments" [37: 1] with politics, and thus the state, being integral to their creation and functioning.

Consequently, the institutionalist paradigm assigns a far more active role to the state in relation to the market. Market outcomes result from a myriad of institutional arrangements and processes all of which are influenced by the state and politics. Accordingly, a view of market outcomes solely in terms of output and price provides a partial and thus inaccurate view, of reality. The corollary of this paradigm is that energy markets need to be considered through a multi-dimensional lens which goes beyond the absolute market notions of output and price to include notions such as adequacy of capacity to meet demand, affordability and sustainability. This approach is more consistent with the European definitions of energy security.

D. The Implications of Energy Security' Specificities

The discussion has shown multiple meanings can be attributed (and have been) to the term 'energy security'. Its meaning may be used to convey absolute and relative notions denoting dimensions of availability, adequacy of capacity, affordability and/or sustainability. Those favouring a narrow market-centric definition place an almost exclusive priority on the absolute dimension of availability i.e. physical supply (although notions around 'adequate capacity' may be mentioned) and affordability is eschewed, not only due to its inherent relativity but because it is generally assumed that market price reflects energy availability and thus the cost of security of supply [39]. Possibly the narrowest market-centric definition of energy security is that posited by [22] as energy availability "to those willing to pay the market price".

The adoption by government of a narrow market-based or broader multi-dimensional definition of energy security is an unequivocal signal of its intended role in the pursuit of energy security objectives. Energy market outcomes are either viewed purely in absolute market terms or more broadly. If the latter, governments may wish to intervene to 'adjust' the market outcome.

The discussion has also shown that energy security is a concept and policies may be directed at implementing its strategic intent which often is framed in terms of: (1) the management of perceived risk(s) – to avoid supply disruption, insufficient capacity, unaffordability, and reliance on unsustainable energy sources, and/or (2) a country's energy use mix and reliance on local resources or imports. The time horizon adds a further layer of complexity to the meaning of energy security because whatever dimensions are used to define the term, the risks or threats to those dimensions will differ in the short term from the long term. Finally, the heterogeneity between energy markets means that the application of the concept will result in different meanings for different energy sources.

These findings lead to the contention that the concept of 'energy security' is inherently slippery because it is polysemic in nature. The concept has many possible meanings. Energy security may be delineated through multiple dimensions and takes on different specificities depending on the country (or continent), timeframe or energy source to which it is applied.

Traditionally many problems for policy makers could be resolved by the systematic application of technical expertise [40]. But contemporary governments around the world have increasingly confronted very complex problems, problems so complex that they have been termed 'wicked' because of being seemingly intractable or highly resistant to resolution. These problems require new ways of thinking and pose substantive challenges to governance structures, skills bases and organisational capacities [41]. Given the polysemic layering in which energy security is swathed, does this make it a 'wicked' problem?

III. Is Energy Security a Wicked Problem?

Rittel and Webber [42] observed that a range of planning problems were not amenable to being treated with traditional, linear analytical approaches denoted by the sequential top-down process of problem definition, data collection, analysis, formulation of a solution and implementation. This logic of working from the problem to the solution is common and familiar. The starting point is an understanding of the problem. After the problem is specified and its dimensions analysed, a solution is formulated followed by implementation.

Policy problems not amenable to such treatment have been designated 'wicked' not "in the sense of [being] evil, but as a cross-word puzzle addict or a mathematician would use it – suggesting an issue (or problem) difficult to resolve" [43: 1]. Wicked problems are distinguishable from 'tame' or 'benign' problems. Tame problems are not necessarily simple and can be very technically complex. But these are problems that can be more readily defined and a solution more easily identified. Many of the policy challenges confronting governments today are complex, contested and seem intractable despite considerable resources allocated to resolve them. There is no obvious or easily found solution. These are wicked problems. Examples of these policy challenges include climate change, terrorism, obesity, poverty, and indigenous disadvantage. Can energy security also be designated a wicked problem?

Wicked problems are distinguishable by multiple characteristics although not all need to be displayed for a

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problem to be deemed as wicked. The generally agreed common characteristics of wicked problems cited in the literature are: difficulty of clear problem definition; no clear solution; solutions are good-or-bad not right-or-wrong; unintended consequences arise from solutions; inability to implement solutions by trial-and-error; infinite solutions; uniqueness; solutions involve multiple organisations and governments; and, behavioural changes are often required to solve wicked problems [41]-[49].

These characteristics do not categorise a given problem as wicked or not per se. Rather these characteristics provide policymakers with "a sense of *what contributes* to the 'wickedness' of a problem" [44: 16, emphasis added]. We will now consider each of these characteristics in turn, although it will be seen that they are strongly interrelated, and assess whether any can be attributed to energy security in light of its qualities found earlier. I am not aware of any previous assessment to determine if energy security is a wicked problem. Paquet [46] assessed the suitability of a research method based on social learning to energy policy. He assumed from the outset that 'energy policy poses a wicked problem' because of inherently similar characteristics to wicked problems and he did not conduct a 'wickedness' assessment.

A. There is No Definitive Formulation of the Problem

The nature and extent of a wicked problem varies depending on who is asked. Different stakeholders have different views about the nature of the problem and thus, the nature of what represents a satisfactory solution. Each proffered solution presents different aspects of the problem because "every specification of the problem is a specification of the direction in which a treatment [solution] is considered" [42: 161]. In other words, the formulation or specification of a wicked problem *is* the problem. To define the problem is the equivalent of finding a solution. The problem cannot be defined without reference to a solution but there will be different versions of the solution and thus, different views of the problem because of the different perspectives held by stakeholders.

A very contemporary illustration of this characteristic of a wicked problem is the debate concerning the causes and solutions to climate change. According to Thompson and Verweij [50], the climate change debate can be distilled into three competing versions – profligacy, lack of global planning, and much ado about nothing. Each version emphasises different aspects and proposes different solutions. Each version presents a plausible but different explanation of climate change. None are completely right and none are completely wrong. Each focuses on a partial aspect of the debate [41: 5].

With respect to energy security, the earlier discussion delineated the use of two broad definitions. One definition is framed narrowly around the market-centric terms of output (supply) and price. This definition is based on the paradigm of a pure Walrasian market with its self-equilibrating properties. Markets are assumed to clear automatically through price responding to demand or supply changes. Accordingly, competitive markets and 'independent' regulation are considered to be the most effective solution to delivering secure and reliable energy. This conceptualisation sees a limited role for governments and policy.

The alternative definition of energy security, we saw, embraces dimensions other than market supply and market price such as adequacy of capacity, availability, affordability and sustainability. This definition is underpinned by a different market paradigm which situates the market as one of capitalism's multiplicity of institutions and considers an active interventionist state to be integral to the creation and functioning of energy markets. Hence, energy security – in this case - is viewed as a market outcome resulting from institutional arrangements and processes orchestrated by the actions and policies of the state not the result of self-equilibrating forces.

Thus we have two different formulations of the problem of energy security and two different approaches to the solution. This is consistent with the first characteristic of wicked problems.

There is another feature of energy security which also meets the criterion of 'no definitive formulation of the problem'. We have seen that energy security can assume different specificities. The nature of the problem can be expressed in terms of a country, a continent, a region, end-users or even a particular energy market. The problem of energy security for a country with high import dependence will be defined far differently, as will be the policy solution, than that for an end-user such as a household. Fuel diversification, a geographic spread of energy supply sources and a reduced dependence on particular energy sources could possibly dictate the proposed solution to a country's energy security. In comparison, the energy security of a northern hemisphere household may be described in terms of the availability and affordability of reliable energy sources for cooking and heating. Alternatively, the security of electricity supply could be characterised around the availability and cost of fuel sources, generation capacity, transmission and distribution infrastructure and market operations. Each is a different conceptualisation of the problem of energy security, and its solution. This meets the first criterion of wicked problems to have 'no definitive problem formulation'.

B. There is No Absolute or Clear Solution to the Problem

The second characteristic of wicked problems is partly a corollary of the first. If there is no definitive formulation of a wicked problem, there can be no clear or absolute solution or a clear end point to its resolution.

The priority afforded a wicked problem may vary over time not for reasons inherent to the problem but due to external considerations such as the exhaustion of resources applied to the problem or a change to the political priorities of government. But this does not mean that the wicked problem has been eliminated. Such is the nature of its complexity and difficulties of definition that a wicked problem may never be

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completely solved or eliminated (e.g. illicit drug use). Wicked problems persist, they are intractable and subject to redefinition because its nature evolves over time as governments implement policy actions to address the problem [45: 6].

Just as the first wicked problem characteristic has applicability to energy security so does the second characteristic. The multiplicity of meanings that can be attributed to energy security establishes that there can be no 'one-size-fits-all' solution. For example, the policy measures designed to reduce a country's energy import dependence will differ considerably from the policy measures aimed at improving energy affordability. Both can be denoted as dimensions or aspects of energy security but each requires considerably different policy formulation, policy instruments and implementation given the vast difference in the nature and scale of impact sought.

The temporal dimension of energy security also signals the impossibility of an absolute or clear end-state solution. It was noted earlier that the meaning of energy security will differ over the short, medium and long term because the probability, likelihood and consequences of different risks or threats to supply will vary over time. Thus we will never reach an end-state of energy security as such. An analogous situation is the process of competition. Firms continually seek to create and maintain the best conditions for their profitability. To do this, firms will continually seek out and exploit differences in technology, production, distribution, access to information and consumption trends. It is an ongoing never-ending process. Likewise policymakers and governments will take actions seeking to remove the obstacles deemed to be preventing energy security. But the factors influencing energy security, however it is defined, are constantly changing. Hence, an end-state of energy security is never reached because it is an evolving allegory with multiple meanings. Energy security meets the second criterion of wicked problems.

C. Solutions to Problems are not Right-or-Wrong

This third wicked problem characteristic logically follows from the second. We have already seen that different stakeholders hold different views about what is a wicked problem and thus, what will constitute an acceptable solution. Similarly, given the complexity of wicked problems, stakeholders will judge the solutions to wicked problems differently. These judgements will reflect their respective interests and positions, and will be expressed in relative terms such as 'good', 'bad, 'better', 'worse', 'good enough' or 'not good enough'. For wicked problems, there are no right or wrong solutions. For wicked problems, there are no conventionalised criteria (like the formula for a chemical compound) against which solutions can be evaluated and an unambiguous answer derived.

We previously observed that an end-state of energy security is not possible given that constantly changing factors shape its multiple meanings and temporal dimensions although policies will be implemented to remove perceived obstacles preventing energy security. It was also noted earlier that definitions of energy security may contain the relative and/or absolute notions of sustainability, affordability, availability and the adequacy of capacity. The latter refers to the net outcome of demand for energy and the capacity available to provide energy in response to that demand. Policies designed to improve the adequacy of capacity may include demand management and energy efficiency programs, taxation and other incentives to stimulate investment in renewable energy sources to provide additional electricity generation capacity, along with other measures. Governments will evaluate the efficacy of each policy measure to determine, amongst other things, if it has *improved* the adequacy of capacity through, for example, a reduction in the growth rate of the demand for energy or the amount of additional capacity to existing energy infrastructure. Yet there will be divergent views about the effectiveness of these policy measures because there is not a common definition of the problem or solution, and thus different criteria will be used to assess the outcomes of policy measures.

Having met the first wicked problem characteristic, it is probably not surprising that energy security meets the second and third characteristics given that these logically flow from the first characteristic.

D. Solutions will Often Lead to Unforeseen Consequences

For tame problems, the effectiveness of a solution can be easily tested. For wicked problems which are multi-casual with many interconnections to other issues, solutions to address the problem commonly lead to unforeseen consequences elsewhere over an extended period of time. These consequences may outweigh the intended advantages of the solution. Yet it is not possible to appraise these consequences until "the waves of repercussion have completely run out, and we have no way of tracing *all* the waves through *all* the affected lives ahead of time or within a limited time span" [42: 163]. Moreover unintended consequences will, in every probability, spawn new wicked problems.

It was noted earlier that the world's escalating consumption of fossil fuels is the key contributor to the problem of greenhouse gas emissions (GGE). Energy security strategies of the 1970s placed a very strong emphasis on reducing dependencies on oil as a primary energy source. The world's oil appetite did not abate, growing strongly along with a rapidly accelerating use of other fossil fuels. The environmental ramifications of GGE are only now beginning to be addressed at a global level. GGE are a highly tangible consequence of energy use. Energy security solutions pursued in the late twentieth century did not address these environmental ramifications. Twenty-first century energy security strategies, of for example the EU, are endeavouring to reduce the rate of emissions growth and its absolute level.

Another 'consequence' of policy solutions designed to improve energy security concerns the global restructuring of

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electricity sectors. A core feature of this restructuring has been a far greater reliance on the market to determine investment outcomes. The level of wholesale electricity prices is claimed to signal the need for investment in additional generation capacity. However, it has been found that high wholesale prices have not stimulated investment to expected levels in base-load generation capacity because of policy uncertainty about emission trading or other forms of GGE abatement schemes [51]-[53].

A further example of consequences also comes from electricity sector restructuring. The proclaimed objectives of this restructuring included lower consumer prices. However, there is increasing evidence that lower electricity prices for households have not occurred. Some have experienced increases of up to 60%, and increasing proportions of disposable income are required to meet higher electricity bills with considerable hardship being incurred by low-income consumers [54][55]. Governments have subsequently introduced additional policy measures to redress this 'unintended consequence' such as the UK Fuel Poverty Strategy [56].

These three examples demonstrate consequences arising from policies intended to improve energy security and consequences which were at odds to the intended outcomes of these policy actions. However, it is more difficult to conclude these were all unintended consequences. An absence of policy action 30 years ago to address GGE does not mean that policymakers were ignorant of the occurrence of these emissions. It does signal it was not a political priority at that time given the absence of policy attention. It also signals a lack of knowledge – at that time – of the long-term impact and scale of environmental degradation caused by rapidly escalating fossil fuel use compared to our understanding now. 'Unintended consequences' would seem to be an inevitability of lack of knowledge.

Our second example, of investment in electricity base-load generation capacity being stymied by policy uncertainty concerning GGE, signals that policymakers had a narrow understanding of the critical influences on investment decisions in this particular form of infrastructure. Policy myopia may have led to unintended consequences rather than the solution to the wicked problem per se.

An analogous issue is apparent with respect to our third example of significant increases in household electricity prices. Electricity sectors have been restructured to create competitive markets which, according to the underlying theory, provide the most efficient allocation of resources. Lower prices were heralded as an expected outcome. There is evidence of lower prices for some consumers – business – but not for the household sector. Criticisms of the substantial increases in household electricity prices have been rebuffed by restructuring advocates with arguments such as 'the prices now reflect a truer cost of supply' and thus a more efficient allocation of resources [2: 252-59]. These price increases for households were not foreshadowed prior to the restructuring in stark comparison to the detailed estimates released of the projected impacts on household electricity prices of emissions trading [For example, 57]. To suggest this could have been an unintended consequence of electricity sector restructuring would be disingenuous. Price impacts were foreshadowed by policymakers but not negative ones.

This discussion highlights the difficulty in concluding that solutions to the problem of energy security have led to unintended consequences as is alleged to occur from the solutions to wicked problems. These consequences may well occur. Further evaluation is required to reach a more definitive conclusion with respect to energy security.

E. Solutions cannot be Implemented by Trial and Error

According to [42], there is no opportunity to learn by trial-and-error with solutions to wicked problems. Every implemented solution for a wicked problem is consequential. The solutions leave 'traces' and are effectively irreversible, a good example of which is large-scale infrastructure projects. Solutions are expensive due to the complexity, multi-causal nature and interconnectedness of the problem.

Nuclear power plants would seem to exemplify this wicked problem characteristic. Conceived as a solution to improve the security of energy supply, nuclear plants provide around 16 per cent of the world's electricity generation capacity. They are very expensive to build with construction times increasing from around 6 years in the 1970s to nearly 10 years by the turn of the century. Construction costs around the world have consistently exceeded budget, in some cases by 300%. Decommissioning and waste disposal takes the equivalent of many times the plant life [currently more than 100 years], the costs of which have also risen exponentially. Production costs generally fall over time due to technological improvements, economies of scale and efficiency improvements. However, the rate at which this has occurred for nuclear power has been much lower than all other technologies [58], [59]. On the other hand, nuclear power plants emit considerably less greenhouse gas than coal or oil fired power plants which starts to change the comparative costs of electricity with the introduction of emission trading schemes as well as be more compatible with environmental policy objectives.

The cost and lead time of construction make nuclear power plants an expensive commitment. Like all major capital projects, a point of 'no return' is reached in the construction phase where the costs of cessation significantly outweigh the costs of proceeding. Upon completion the project may not yield the projected benefits as has occurred with the changing economics of nuclear plants notwithstanding the more recently perceived environmental benefits of nuclear power. Decommissioning and waste disposal are two very tangible outcomes of nuclear power that are 'irreversible'.

Another possible energy security example which falls within the ambit of this wicked problem characteristic is the creation of the UK electricity wholesale trading pool. This was to be the primary market for trading electricity. All electricity generated had to be sold via the pool. Eleven years after commencement, due to a number of reasons, the pool

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was replaced with a trading system based on bilateral contracts. The cost, to the UK government, of establishing and operating the trading pool for the first five years was £726 million. The cost to develop and operate the replacement trading system over its first five years has been estimated at £1 billion [60]. Apart from being costly, this policy change was tantamount to a 180 degree turn and thus cannot be labelled policy incrementalism, of making changes to existing programs [61]. There was no turning back to operating the UK electricity sector to 'the way it was' because a number of concurrent changes such as de-integration and privatisation ensured the sector's structure bore little resemblance to that of pre-trading pool days.

Markets for the wholesale trading of electricity have become a core feature of restructured electricity sectors around the world since the early 1990s [2: 16-26]. Despite some design and operational differences, these markets have now become inextricable to the operation of this industry sector and the electricity supply chain. Considerable resources of government have been expended in their creation and ongoing regulation. As in the case of the UK and the high profile example of the Californian electricity market [62], should these electricity markets change in any way there will be no return to the circumstances which prevailed prior to their inception. The operation of these wholesale markets has led to an array of other significant structural changes such as market consolidation and concentration, the regulation of monopoly functions, the re-integration of generation and retail activities, and the trading of electricity derivatives to hedge the risk of price volatility in electricity wholesale markets. These changes are consequential to the creation of wholesale electricity markets and cannot be reversed should there be any alteration to the wholesale trading of electricity.

Nuclear power plants and wholesale electricity markets do illustrate that solutions implemented for the purpose of 'solving' energy security can have consequences, be very expensive, leave 'traces' and are effectively irreversible. Therefore energy security also meets this characteristic of wicked problems.

F. Infinite Solutions

"There are no criteria which enable one to prove that all solutions to wicked problems have been identified and considered" [42: 164]. Policymakers consider a range of potential solutions in the pursuit of wicked problems. But many solutions are not even contemplated because there are an infinite number of solutions. It is a matter of judgement for policymakers to determine if the 'set of solutions' considered should be expanded. It is also a matter of judgement by policymakers and decision makers which solutions are the most feasible to be pursued and implemented.

This wicked problem characteristic logically follows from the earlier discussed characteristics of no definitive problem formulation and thus, no absolute or clear solution to the problem. If a problem can be conceptualised in different ways, as we have seen with energy security, there will be multiple solutions. These solutions will be innumerable when multiplicity of problem definition prevails.

G. Each Wicked Problem is Unique

There are so many factors and conditions contributing to the complexity of a wicked problem that no two wicked problems are alike, and the solutions to them will be tailored to meet the unique nature of each.

> There are no *classes* of wicked problems in the sense that principles of solution can be developed to fit *all* members of a class ... Despite seeming similarities among wicked problems, one can never be *certain* that the particulars of a problem do not override its commonalities with other problems already dealt with [42: 164-65, original emphasis].

A problem analogous to energy security is that of food security. There is a longstanding and wide-ranging discourse about food security fused around notions of availability, affordability, accessibility and utilisation [63]-[66]. Food security solutions are directed at a complex system which encompasses: those who grow or catch food; the physical environment; food processing, packaging, distribution and marketing; food wholesalers and storage; the transportation system; the retailing of food; places where food is served such as health or penal institutions; the political and economic environment; the health care system, the workforce, schools and technology; and everyone who consumes food. The word 'energy' could easily be substituted for 'food' in this system description and the result would be a very accurate depiction of the complex of system elements which impact on, and are impacted by, energy security. Yet the same 'substitution' is meaningless when it comes to the causes of food insecurity and proposed solutions notwithstanding that energy security may also have dimensions such as availability, affordability, accessibility and sustainability.

The multiple causes of food insecurity include: insufficient economic resources and lack of a political voice; poor water resources and environmental degradation; unequal gender access to education, training, land ownership and credit; population growth and urbanisation; trade barriers; and droughts, floods, cyclones and pests [67]. Solutions are framed around national and global strategies to improve food production, economic growth and trade liberalisation, policy and behavioural changes, gender equality and food aid. Yet the solutions recommended to overcome food insecurity cannot be replicated as solutions for energy security given the very unique specificities of each. We saw earlier that the multiple dimensions of energy security can be reflected through different specificities depending on the country (or continent), timeframe or energy source to which it is applied. It is to these unique specificities that solutions to the problem of energy security are directed just as food security solutions are directed to its particular specificities. Each concept is able to be defined in similar relative and absolute dimensions but their specificities are peculiar to each. Consequently, it can be concluded that the solutions to the problem of energy security

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are unique. This satisfies another characteristic of wicked problems.

H. Solutions Involve Multiple Organisations and Whole-of-Government Approaches

Wicked problems require holistic rather than linear thinking given their complexity and multi-causal factors [43]. This complexity, causality and interconnectedness also mean that wicked problems defy 'organisational neatness' and require a capacity to work across organisational and governance boundaries. The effectiveness of solutions will be maximised by crossing organisational boundaries and adopting whole-of-government approaches at local, national and international levels although over a sustained period this can be complicated, costly and difficult to effect [41: 17-19]. Inter-organisational, whole-of-government and inter-government working is not easily achieved given that each organization or government has its own priorities and ways of working which may limit the willingness or commitment to tackling the wicked problem apart from the obvious issue of coordination [43].

The restructuring of energy sectors to improve energy security displays features strongly indicative of this wicked problem characteristic. For example, the EU's electricity and gas sectors have been transformed by a number of policy directives requiring all 27 member countries to implement a range of structural changes such as separation of competitive and monopoly functions, introduction of retail competition, provision of third party access to monopoly networks, creation of wholesale trading markets and national energy regulators, application of minimum operating standards, monitoring of capacity and demand as well as preparation of national network investment plans for regulatory approval [68]-[73]. Each EU member country has been required to implement these changes through their respective national laws. In addition, the EC established a European Regulators Group to ensure *inter alia* consistent application and timely implementation of the policy directives across all member countries [74], [75]. Regular reports have publicly reported progress and issues arising [76]-[79]. The restructuring process is continuing after more than a decade. The timeline alone points to the inherent complexity of the changes implemented. Moreover, the difficulties of achieving consistent and concurrent implementation across nearly 30 national governments, reflected in the lack of uniformity and unification, led to policy changes, an inquiry into the gas and electricity markets and further legislative packages designed to achieve greater competitiveness, sustainability and security of supply [32], [80].

A similar situation is evident in the restructuring of other electricity sectors such as Australia, a country of similar land mass to Europe and the United States but with a far lower population density. The Australian sector's restructuring was first mooted in the early 1990s and through a series of inter-governmental agreements, involving all six States and two Territories, the restructuring was the cornerstone to a nearly decade-long program of measures to implement a national competition policy. Former government monopolies were broken up into multiple companies, sales of former government businesses contributed significantly to one of the world's largest privatisation programs, a mandatory national electricity market has been operating since late 1998, retail contestability for all electricity consumers has been progressively introduced, and new national and State government regulatory authorities have been established [2: 32-46]. However, government inquiries in 2002 and 2006 were instigated to examine the impediments to energy market reform leading to regulatory regime changes to eliminate perceived obstacles, improve competitiveness and accelerate the changes agreed by all Australian governments [51]. Like the EU, the process of reform has involved a multiplicity of governments and organisations. The most heavily populated States on the eastern seaboard and the southern part of the continent have formed the national electricity market but a plethora of local political issues have led to State-by-State timetables for the introduction of critical structural changes. The western and northern jurisdictions have been required to mimic, to the extent possible, the changes of the other States because geographic remoteness precludes national market integration.

It could be argued that the problems experienced with electricity sector restructuring are solely due to the sheer number of organisations and governments engaged in the reforms and the consequential inherent coordination difficulties that this brings. But such an argument overlooks the fundamental reason for the involvement of so many institutions. The sectoral restructurings deemed to contribute pivotal short and long term solutions to energy security could not be achieved by one organisation or one level of government. The solution required inter-organisational and inter-government agreement, co-operation and active participation over a period extending to more than a decade. This is strongly symptomatic of the eighth characteristic of wicked problems, namely solutions requiring multiple organisation and government approaches.

I. Solutions Often Involve Changing Behavior

Governments use a range of policy instruments to achieve desired changes. These policy instruments are the "set of techniques by which government authorities wield their power" [81: 21] and "to shape our lives … to suit a variety of purposes" [82: 2]. Policy instruments are forms of intervention by government aimed at the behaviour of citizens, firms and other organisations. These instruments may take one of three broad forms:

- regulation – rules and directives which require certain behaviour and may include the threat of negative sanctions such as fines or some form of punishment. These are mandatory rules of conduct;
- economic – involve either the handing out or taking away of material resources. These may be monetary or non-monetary forms such as grants, rebates or refunds.

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Economic policy instruments do not prescribe or prohibit particular behaviour. These instruments make types of behaviour more or less expensive; and

- information – influences behaviour through knowledge transfer, communication of reasoned argument and persuasion. No obligation or coercion is involved. Information may be about the nature of the problem, how people are handling a problem, measures to change a situation or reasons to adopt measures.

The solutions to many wicked problems involve sustained behavioural changes requiring a mix of policy instruments [41], [43].

What behavioural changes may be required to address the problem of energy security? One example is evident from our earlier discussion of the concept of energy security. The definition of energy security may be framed in terms of a continent's energy use mix and its reliance on imports. The EC has developed an energy security strategy to minimise the EU's vulnerability of a high reliance on gas imports and ensure sufficient supply through policies such as demand management, energy supply diversification, stimulation of investment in adequate capacity, improved energy access and emergency preparedness [31], [32], [80].

The effectiveness of these policies requires sustained behavioural changes by all participants in the energy sector be they government institutions, producers, distributors, retailers or users. Consequently, a range of policy instruments have been applied. These include *inter alia*: an information campaign on energy consumer rights; directives requiring member countries to maintain minimum energy stocks, to improve the energy efficiency of all new and existing buildings, to label energy efficiency information on all industrial, commercial and household products; to develop cogeneration of heat and power; the provision of information about the benefits to member countries of regional offshore wind energy initiatives; the setting of targets for renewable energy's share of total energy use; and, reporting of obstacles and intended actions by the EC to achieve a competitive internal energy market by regulation. Member countries have subsequently responded with a range of their own policy measures such as separation of electricity generation, transmission and retail functions, the introduction of retail contestability for electricity and gas, product labelling of energy efficiency, solar power feed-in tariffs to encourage takeup, tax exemptions for biofuels to stimulate expansion, and funding for the development of renewable energy technologies and integration with the existing electricity transmission grid.

Although the above description of policy instruments is a very truncated summary, it does illustrate the various types of instruments used to instigate a long-term shift in the behaviour of a range of energy sector participants as part of the EU's energy security strategy. It also illustrates that another wicked problem characteristic can be applied to the problem of energy security.

IV. Conclusion

An examination of the concept of 'energy security' has found it to be inherently slippery, being able to assume a range of meanings and thus polysemic in nature. A subsequent assessment against the commonly-cited characteristics of wicked problems found strong affirmation that energy security is a wicked problem.

Wicked problems are characterised as being difficult to define, having many interdependencies, being multi-causal, leading to unforeseen consequences, evolving as steps are being taken to address it, having no clear solution, being complex, being the responsibility of more than one institution or government, involve changing behaviour and/or being seemingly intractable. A tame problem, on the other hand, has a well-defined and stable statement of problem, has a definite point when the solution is reached, has a solution capable of objective evaluation as right or wrong, belongs to a class of similar problems able to be solved in similar ways, has solutions that can be trialled and abandoned, and has a limited set of alternative solutions.

This means that traditional, linear analytical approaches and the systematic application of technical expertise are inappropriate policy responses to tackle the problem of energy security. This wicked problem requires different ways of thinking and poses challenges to governance structures, skills bases and organisational capacities. Unless this is recognised by governments, decision-makers and policymakers, policies designed to deliver energy security will be ineffectual.

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