COMMITTED TO IMPROVING THE STATE OF THE WORLD

Industry Agenda

New Energy Architecture
Enabling an effective transition

World Economic Forum In partnership with Accenture

Contents

Preface

Roberto Bocca,
Senior Director, Head of Energy Industries World Economic Forum

Espen Mehlum,
Associate Director, Head of Knowledge Management and Integration Energy Industries, World Economic Forum

The world's energy architecture – defined as the integrated physical system of energy sources, carriers and demand sectors shaped by business, government and civil society – is in a state of transition. During a private session at the World Economic Forum Annual Meeting 2011 in Davos-Klosters, Switzerland, 90% of participants, consisting of executives of the world's largest energy companies, policy-makers and thought leaders from across the energy value chain, expressed a belief that significant change is underway in energy architectures around the world. Almost one-third said they believe the world has reached an inflection point that marks a radical shift in the way in which we source, transform and consume energy.

While the pressures and possibilities for change in energy architecture are at a historic height, what is less clear is what shape the transition will take. What will the New Energy Architecture look like? What enabling environment will create the most effective transition towards an energy architecture needed to meet tomorrow's energy requirements for different countries and globally? How can we ensure that the New Energy Architecture goes further to underpin the sometimes competing needs of economic growth and development, environmental sustainability, and energy access and security?

Created to assist decision-makers, the World Economic Forum is pleased to present this report on how to enable an effective transition to a New Energy Architecture. The New Energy Architecture project is conducted under the Forum's Energy Industry Partnership and involves a range of business, government and civil society constituents from the energy and other related sectors.

Through the project, a methodology has been created that identifies the critical points of intervention that can impact the effectiveness of the transition to a New Energy Architecture and more effectively underpin economic growth and development, environmental sustainability, and energy access and security. This includes the creation of an Energy Architecture Performance Index (EAPI), a tool designed to help countries monitor the progress of their transition, as well as the completion of detailed country studies on Japan and India.

The World Economic Forum partnered with Accenture and collaborated with Industry Partners and other constituents to drive the dialogue and research. Representatives from 28 global companies, government agencies and civil society are actively involved, including ABB, the Akio Morita School of Business, AMEC, BASF, Chevron, CH2M Hill, Cisco, Climate Group, DTEK, The Economist, Eskom, HCL Technologies, Hewlett-Packard, Huawei, Intel, International Electrotechnical Commission, the International Energy Agency, Mercuria Energy, Nalco, Novozymes, Powertech Labs, Renewable Energy and Energy Efficiency Partnership (REEEP), REN21 Renewable Energy Policy Network, Royal Dutch Shell, Sasol, Standard Chartered Bank and the United Kingdom Atomic Energy Authority.

Representatives from these organizations contributed strategic direction and thought leadership through a steering board and task force, whose members are listed in the Appendix. Through workshops in Brazil, South Africa, Austria, Indonesia, France, the United Kingdom, China, Japan and India, the project has engaged further leaders of business, government and civil society.

An evolving landscape: Energy architecture "by the numbers"*

$38 trillion

Global investment required in energy supply infrastructure between 2011 and 2035

90%

Share of energy demand growth that non-OECD countries are estimated to account for between 2010 and 2035

7 billion

Global population as of 31 October 2011, rising from 6 billion in just 12 years

97 GW

Global renewable electric capacity additions in 2010, compared to 92 GW of fossil capacity additions

20%

Share of total global electricity supplies from renewable capacity, including hydropower

$211 bn

Total investment in renewable energy, up from $160 bn in 2009

$660 bn

Cost of fossil fuel consumption subsidies in 2020 without further reform, up from $409 bn in 2010

370 GW

Current global nuclear generation capacity, with 1,200GW targeted by 2050

40%

Increase in energy consumption between 2009 and 2035

1.3 billion

Number of people without access to electricity

3.5°C

Long-term global temperature increase based on the emissions trajectory of the IEA's New Policies Scenario

251 mn

Smart meters installed globally, forecast to hit 535 mn by 2015

118

Number of countries with a policy target and/or support policy related to renewable energy, compared with 55 in early 2005

2010

The year in which Sweden met its 2020 target for total electricity generation coming from renewables

10,129

The number of new wind turbines installed in China in 2009 – equivalent to more than one installation per hour

75%

Share of fossil fuels in primary energy consumption in 2035 compared to 81% in 2010

74

Number of large-scale integrated carbon capture and sequestration projects planned, with 14 either in operation or under construction providing 33mn tonnes sequestration capacity annually

51%

OPEC market share in 2035 compared to 42% in 2010

84

Global number of LNG regasification sites with a further 43 planned

4.8 tcf

US dry shale gas production in 2010, up from 0.39 tcf in 2000

* Sources: International Energy Agency, World Energy Outlook, 2011; REN21, Renewables 2011 Global Status Report; China Wind Outlook, Global Wind Energy Council, 2010; Pike Research, Smart Meter Market Forecasts, 2011; IEA, Nuclear Roadmap, 2010; Global CCS Institute, The Global Status of CCS2011; EIA, World Shale Gas Resources An Initial Assessment of 14 Regions Outside the United States

Executive Summary

Momentous changes in the energy landscapes of the past, such as the rise of the steam engine in the 1800s and widespread electrification in the 1900s, have driven profound developments in the wider economy and helped to shape and develop modern societies. Today, we are again moving to a New Energy Architecture – one with lower and non-carbon fuels, increased electrification with greater interconnections and a leaner system – as we strive to do more with less.

Now more than ever, decision-makers must understand the core objectives of energy architecture – generating economic growth and development in an environmentally sustainable way while providing energy access and security for all – and how they are being impacted by changing dynamics.

Responding to these often competing objectives is challenging, as actions to tackle issues such as resource scarcity and climate change must be delivered against the background of difficult economic conditions following the global financial crisis.

The inherent tension between the objectives forces difficult trade-offs to be made. In some instances, decisions are made without a consideration of their broader impacts, leading to flux in the system and uncertainty for industry and investors.

A methodology to assist decision-makers

This research was initiated to help decision-makers drive an effective transition, based on a holistic approach that takes into account the impact of decisions across the energy value chain, and the need to balance competing imperatives.

To assess each country's performance and progress, we have created an Energy Architecture Performance Index (EAPI). The EAPI consists of three sub-indices that explore each objective (economic, environmental and security), enabling policy-makers to understand the broader consequences of their decisions and the trade-offs they imply.

Our assessment has highlighted a number of key trends that are common to groups of countries. These similarities often relate to a countries' stage of economic development and the extent of their natural resources. They show that countries are making their transition to a New Energy Architecture in very different contexts.

In recognition of this we have created four archetypes, grouping countries that face similar challenges and a similar vision for a New Energy Architecture. The archetypes are intended to provide a new framework for thinking about energy transitions, recognizing that there is no one-size-fits-all model. The archetypes consist of nations looking to:

- Rationalize and re-organize mature energy systems
- Capitalize on significant hydrocarbon resources
- Grow their energy supply to support economic expansion
- Access basic energy services at affordable prices

Four enabling pillars

Analysing countries in each archetype that have created strong enabling environments reveals four mutually supportive pillars that are common to all:

- Policy initiatives to put in place the rules, price signals and risk-return incentives that attract investors and facilitate development
- Technology and infrastructure to address specific challenges in a country or stage of the value chain
- Market structures enabling producers to meet consumers' needs efficiently
- Human capacity to drive change and develop solutions

Flowing across the four pillars is the exchange of information, which will be critical to ensuring an integrated approach and driving public engagement.

Given that energy architecture is both a local and global issue, in creating enabling environments each nation needs to understand the broader implications of their actions as well as the international constraints they may face. Scale and complexity are also critical considerations. They demand a patient and incremental approach that may mean it is not until after 2030 that we will see a firmly embedded New Energy Architecture as the cumulative effect of innovation across the four pillars takes hold.

The role of stakeholders in meeting the New Energy Architecture challenge

Three key groups of stakeholders have a role to play: government, industry and civil society. Based on the findings of our research, we believe that stakeholders should take the following steps to enable an effective transition and meet the New Energy Architecture challenge:

1. Understand the trade-offs being made in driving change, reducing the economic impacts of the write-down of legacy assets. This is particularly relevant for those with large legacy systems in place, as in the majority of OECD countries.

2. Consider boundary constraints, both internal and regional, when making decisions with regard to New Energy Architecture. The availability, or lack, of physical elements such as land and water to facilitate change, as well as the capacity of social elements to enact change, should shape decisions.

3. Benchmark progress, measuring performance over time to provide transparent insight into challenges and provide a solid basis from which to make policy and investment decisions, and prioritize opportunities for improvement.

4. Learn from archetypes, to better understand the varying costs and benefits of different transition strategies, and to learn from the successes and failures of those who face a similar set of challenges.

5. Create mutually supportive enabling environments, taking advantage of each of the four pillars and ensuring that there is no weak link in the chain.

Energy transition calls for practical solutions

Simon Henry, Chief Financial Officer, Royal Dutch Shell, Netherlands

As this report so clearly underscores, governments and society face a complex challenge managing the world's transition to a more sustainable energy system, while simultaneously increasing energy supplies to meet surging global demand. The exact course and speed of the transition will depend greatly on the policies governments adopt, as well as how companies and individuals behave in response.

This report rightly emphasizes how striking the right balance between economic growth, environmental sustainability and energy security will entail trade-offs and difficult choices for government policy-makers and society. Indeed, for many countries there is likely to be a gap between what is desirable and what is doable. So their focus must be on practical, cost-effective solutions that produce results.

There is no single way forward. Each country must work with its own resources and constraints to determine the best approach. This report lays out a useful conceptual framework for the factors and trade-offs countries must consider as they shape energy policy and chart a path to the future. It also proposes for the first time a performance index to help benchmark progress in all three areas: economic growth, sustainability, and energy security. The index is a good start on building a useful indicator that will no doubt be refined and improved over time, and it should help stimulate the right discussions.

Among the many factors that will shape the future of the world's energy system, a few will play truly critical roles. One is how quickly the world can shift to new forms of energy. History shows that once a new energy technology is proven, it takes about 30 years for it to achieve 1% of the overall market. Biofuels are just now reaching 0.5% of total energy demand, after decades of development and government support. Wind may get to the 1% mark in the next few years, nearly three decades after the first big wind farms were built in Denmark and the US.

New energy sources take time to develop because of the massive scale of our modern energy system, which has been more than a century in the making. And because of the need to build industrial capacity and learn by doing. For instance, today's largest wind turbines are nearly 100 times more powerful than the ones installed in the mid-1980s, and can produce in much lower wind conditions. Wind already attracts 7-8% of the annual total energy investment, which is now well over US$ 1 trillion per annum.

Another important factor will be the magnitude of growth in global energy demand. As the world's population pushes toward 9 billion and living standards improve, demand could double in the first half of this century. And that is assuming we make heroic efforts to improve energy efficiency. Shell's scenarios team thinks renewable energy could meet 30% of the world's energy needs by 2050. That will be a tremendous achievement and will take a concerted development effort. About 60% of demand will still be met by fossil fuels, with the remaining 10% met by nuclear.

To illustrate the magnitude of the task ahead, by 2020 the world will need to replace 40 million barrels of daily oil production. That's four times what Saudi Arabia produces today. And much of it will need to come from resources that have not even been found yet.

Among the practical solutions countries can use to address these challenges, two stand out.

Natural gas can play a critical role going forward, precisely because it addresses all three of the factors identified in this report. It can underpin economic growth, address environmental concerns and enhance energy security. And it requires no new technology development to do so. Generating electricity from natural gas instead of coal can cut CO2 emissions at individual plants by 50-70%. That is important because coal is currently responsible for 44% of the world's energy-related CO2 emissions. Gas-fired generators can ramp up or down more easily than other types of plants, making them important allies to intermittent power from renewables like wind and solar. Natural gas can also enhance supply security in many cases, as new sources are developed. The world currently has recoverable gas resources equal to about 250 years, at current production rates.

Another important step countries can take is to focus on smarter urban development. Cities today hold half of the world's population and generate up to 80% of total CO2 emissions. With the urban population expected to grow more than 70% over the next 40 years, the way in which they develop will greatly affect energy demand. "Smart" cities' technology holds tremendous opportunity, through more efficient public transport, energy-efficient buildings and designs that utilize waste heat and renewable energy sources. By investing heavily to upgrade our infrastructure, we can offset some of the growth in energy demand while creating new jobs.

Government policies are key. Success requires careful assessment of the inherent trade-offs between the three elements of the triangle of imperatives. New technologies need to be mature enough to attract the huge investments required, which in turn can only be financed through market mechanisms. And long-term, stable policies will be needed – a requirement sometimes at odds with shorter term political considerations.

Managing the transition to a more sustainable energy system is one of the major challenges of our age. I feel confident that human ingenuity and frameworks such as those presented in this report will help the world get there. Government, industry and all of society must join forces and accelerate the process.

Challenges and Opportunities on the Transition to a New Energy Architecture

The Global Agenda Council on New Energy Architecture

Effectively addressing the challenges of economic growth, energy security, energy access and environmental sustainability will require a fundamental remaking of energy production, distribution and consumption systems around the world over the coming decades. The Global Agenda Council for the New Energy Architecture met in Dubai, United Arab Emirates, in October 2011 to discuss the possible pathways to address these challenges.

The Council recognizes that energy is a complex issue with a multitude of participants, each with different interests and priorities. The purpose of this note is to highlight key issues to consider as nations look to drive an effective transition.

Significant change is underway in the world of energy and many factors are influencing this change – events, economic factors, energy security concerns, government policies, environmental goals and innovation are the dominant factors driving this change. Since the last Annual Meeting:

- The future of the nuclear sector has become uncertain after the accident at Fukushima
- The Arab Spring has led to significant political change in the Middle East and created uncertainty about future supplies from the region
- The shale gas revolution has started to spread from North America to other parts of the world and the technology is now being applied to tight oil
- Oil prices have reached their highest annual average since records have been kept

Energy Policies

Government policies in every country in the world influence both national and international energy architecture. Given the strategic significance of the industry, this is expected. It is also expected that national interests will continue to dominate energy policies. However, at present, there is a patchwork of policies in most nations and internationally.

Leaders from across the energy spectrum – oil and gas, power generation and low-carbon technologies – should join forces to develop a coherent policy framework for the future. The framework should be based on core principles that address energy security, economic growth and sustainability. Policies that are supporting the transition to a lower carbon future should be supported, but there must be realism about the role that the fossil fuel industry will continue to play for the foreseeable future to help achieve energy security and economic growth. At the root of all policies is the fundamental belief that open borders enhance diversity and security of energy supplies. The global energy system has shown its resilience in the face of crisis and disruptions and any attempts to create barriers should be discouraged. To meet the future demand for energy, investments in excess of US$ 1 trillion per year will be required for the foreseeable future. This presents a significant opportunity for job creation in all parts of the energy sector and policies that support investments in the energy sector should be encouraged.

Energy Efficiency

According to the International Energy Agency's 2011 World Energy Outlook, global energy demand is expected to increase by one-third from 2011 to 2035. Demand-side management is needed to curb the increase as much as possible, with energy efficiency holding the key. Significant improvements in energy efficiency are possible with known technologies. Both transportation and power generation make use of less than one-third of their primary energy input. It is well known that deployment of energy efficiency technologies requires up front capital investment that is paid back over a period of time. There are many other market challenges such as asymmetric information flow and the "principal-agent" problem. There is a lack of a coherent policy framework to address energy efficiency across the world. In the current economic conditions, a focus on energy efficiency is good for everyone – policy-makers, consumers and businesses.

Energy industry leaders should reaffirm their commitment to driving improvements in energy efficiency as a core pillar of the future energy architecture around the world. Policy-makers should also commit to removing barriers for the deployment of new technologies that provide cost-effective solutions to improve energy efficiency. If the leading players in the energy industry do not commit themselves to greater energy efficiency and other demand side improvements, we should expect to see the growth of new entrants from other industries (such as IT), as well as new companies that are starting to capitalize on business opportunities in this space.

Climate Change

According to the IEA, global energy-related emissions of CO2 increased by 5.3% to a record 30.4 gigatonnes in 2010. If this trend continues, it is very likely that the global average greenhouse gas concentrations will exceed 450 ppm. Since the start of the Great Recession, tackling climate change has become increasingly difficult due to fiscal challenges faced by many governments around the world. There is a growing recognition of the need for "adaptation" as well as "mitigation" as witnessed during COP-17 in Durban. At the same time, there is a spurt in innovation in low-carbon energy technologies. The biggest challenge these start-ups face is a lack of capital investment for scaling up their technologies and a lack of understanding of the energy industry structure. A rapid deployment and scale up of new innovations require closer partnerships between the incumbents and new entrants. Incumbents should increase their investments in new high-risk, low-probability technologies and new entrants should leverage the experience and expertise of the incumbents. In the current economic climate, lack of financing has become a major impediment for the scale up and rapid deployment of new technologies. Energy industry leaders should become the catalysts for these partnerships.

Innovation

This decade is crucial for evaluating the multiple pathways to a different and more sustainable energy future. The world is relying on major technological innovations in the energy sector to create this future. The large capital stock on both the demand and supply side of the energy equation makes revolutionary change nearly impossible. However, the energy sector should strive for a fast evolution and rapid scale up of new technologies, from laboratory to large-scale applications. This will require significant new investments in technology development, a new generation of skilled workforces, and new plants and equipment. These investments will enable us to scale up new ideas and identify the technologies that can grow from a US$ 50 million start-up to a US$ 1 billion business. Industry leaders and policy-makers should develop a common framework for energy sector innovation and commit the investments required to tackle this challenge.

New Energy Architecture Enabling an effective transition 8

Conclusion

Rational behaviour and sound business decisions have long been hallmarks of the energy industry. In the past, the industry has worked collaboratively with civil society and governments to develop and support policies that promote economic growth and environmental security. Will this continue to happen in the future? This is the biggest challenge for the industry leaders gathered in Davos. Addressing this challenge is the biggest opportunity to make a real and sustainable contribution to the creation of the future energy architecture.

Members of the Global Agenda Council for the New Energy Architecture:

- Atul Arya, Senior Vice-President, Research and Analysis, IHS
- Miranda Ballentine, Director of Sustainability, Wal-Mart Stores
- Xavier Chen, Vice-president, Policy and Business Integration, BP (China) Holdings Limited
- Tejpreet Singh Chopra, President and Chief Executive Officer, Bharat Light and Power
- Sean M. Cleary, Chairman, Strategic Concepts
- Anoush Ehteshami, Dean of Internationalization, Durham University
- Bob G. Elton, Adjunct Professor, University of British Columbia; and Council Chair
- Arthur Hanna, Managing Director, Energy Industry, Accenture
- Michael Liebreich, Chief Executive, Bloomberg New Energy Finance
- Peggy Liu, Chairperson, Joint US-China Collaboration on Clean Energy (JUCCCE)
- Tatsuo Masuda, Professor, Nagoya University of Commerce and Business Graduate School
- Ricardo Melendez-Ortiz, Chief Executive, International Centre for Trade and Sustainable Development
- Ernest J. Moniz, Professor and Director MIT Energy Initiative, Massachusetts Institute of Technology (MIT)
- Annetta Papadopoulos, Associate Partner, IDEO
- Kristine Pearson, Chief Executive, Lifeline Energy
- Qin Haiyan, Secretary-General, Chinese Wind Energy Association
- David Sandalow, Assistant Secretary for Policy and International Affairs, US Department of Energy
- Vijay Vaitheeswaran, China Business, Finance and Tech Editor, The

Section 1:
The Transition to a New Energy Architecture – Bringing Balance to the Energy Triangle

1.1 A Conceptual Framework for Understanding Energy Architecture

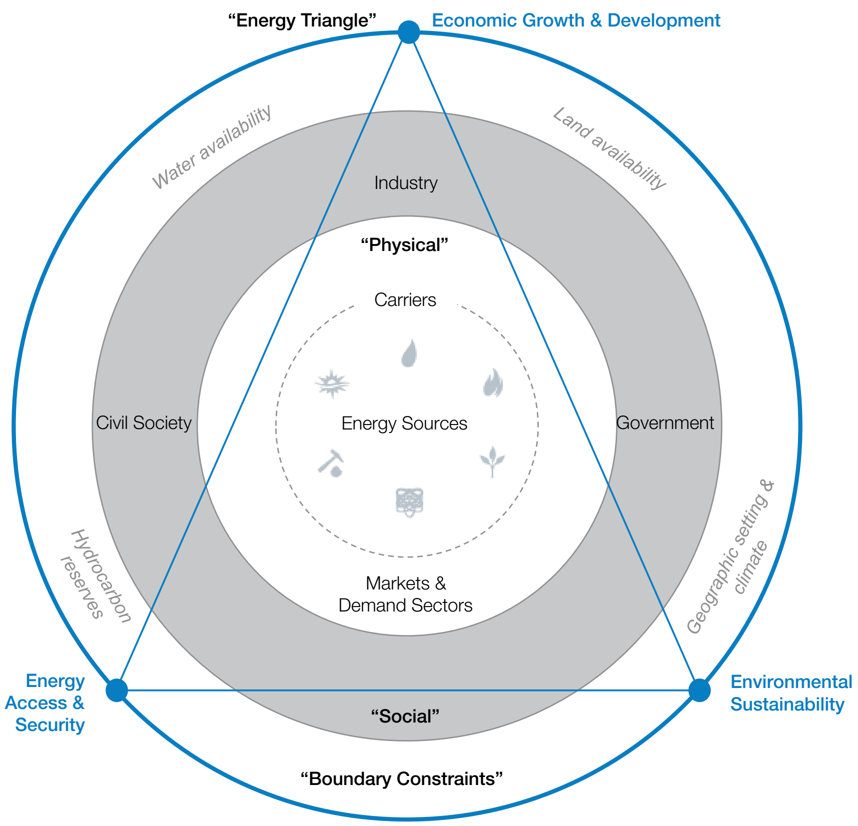
It has been common for some time to characterize the concerns surrounding energy as a "triangle" of imperatives relating to the economy, environment and energy security.[1] To be effective, energy architecture should be designed with these imperatives in mind. Although, it should be noted that delivery against each of them is limited by a set of "boundary constraints".

We define energy architecture as the integrated physical system of energy sources, carriers and demand sectors shaped by government, industry and civil society.

Our conceptualization of energy architecture can be seen in Figure 1. While this is a greatly simplified view, it provides an overview of the complex interactions involved, underlining that a systems-based approach should be taken to managing change.

1 This concept is commonly referred to by the IEA among others, whose mandate has been broadened to incorporate the "Three E's" of balanced energy policy-making: energy security, economic development and environmental protection.

Figure 1 – Energy architecture conceptual framework



Definitions

Physical elements : Includes energy sources, their carriers and end markets.

Social elements : Includes political institutions, industry and civil society, which shape the physical elements.

The Energy Triangle : Ultimate objectives that the energy architecture is designed to support.

Boundary constraints : Factors limiting performance against the energy triangle, both physical and social.

The effect of boundary constraints on energy architecture performance[4]

Boundary constraints limit performance against the three imperatives of the energy triangle. These constraints relate to both physical issues (such as hydrocarbon reserves) and social issues (such as the availability of human capital).

Nations must consider boundary constraints, both internal and regional, when making decisions with regard to New Energy Architecture. Solar technology is a good example: crystalline solar technology is the most economical solution in areas where land availability is scarce or land costs are high; PV is the most economical solution in locations where land is abundantly available as well as in high temperature locations; and, Concentrated Solar Power (CSP) requires availability of water and direct insulation.

Understanding of boundary constraints changes over time. For example, the decision of the US to pursue a concerted drive for liquefied natural gas (LNG) re-gasification capacity in the early part of this decade was based on an assumption that American energy architecture was constrained by a lack of gas reserves. That picture now looks very different, following the discovery of shale gas reserves.

Below we provide examples of boundary constraints. This list is not exhaustive, but is intended to provide an overview of the range of challenges that nations face. These issues are further explored in the below opinion piece by Juan Carlos Castilla Rubio and Wes Frye from the Planetary Skin Institute:

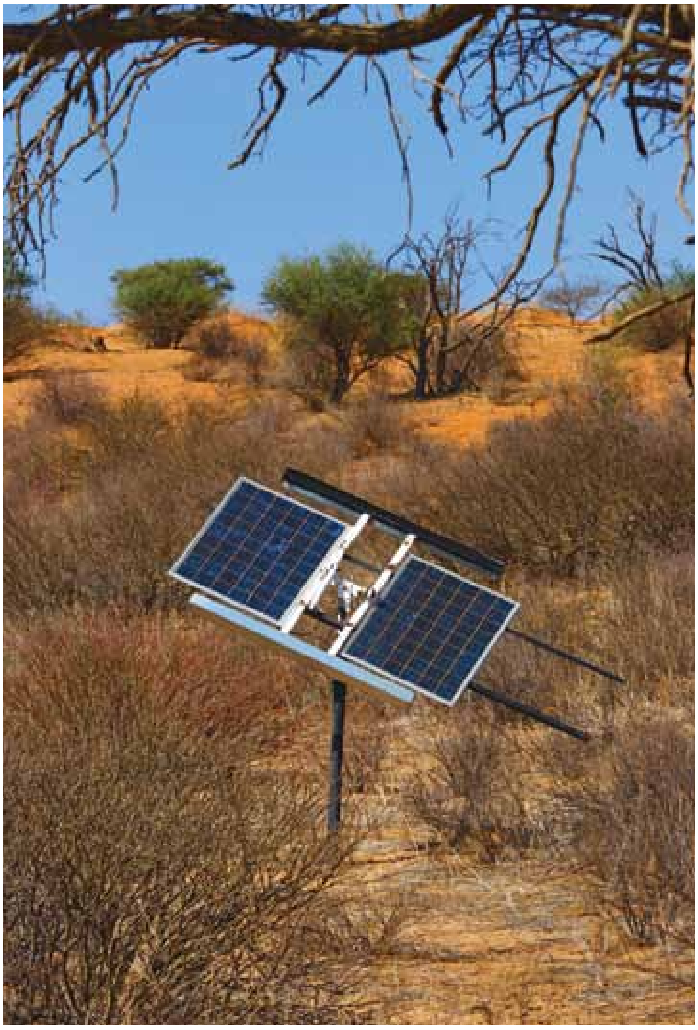
Geographic setting and climate: Energy consumption, particularly with respect to heating and cooling, is a function of geographic circumstances and climatic conditions. For example, in the US, January temperatures are negatively correlated with natural gas consumption and July temperatures are positively correlated with electricity consumption, reflecting heating and cooling needs, respectively. Other climate attributes, such as humidity, also contribute to the specificity of demands for energy. Optimal sources for energy supply also depend on local conditions, such as wind patterns and solar concentration. The use of offshore wind power is particularly suited to the United Kingdom, Norway and Holland, which have the highest potential wind resource in Europe,[2] and additionally seasonal demand correlates well to seasonal variability in wind speeds.

Hydrocarbon reserves: The availability of indigenous sources of hydrocarbons helps determine the nature of energy architectures. For example, those with large reserves, such as Saudi Arabia, have constructed energy architectures that are focused on the production, use and export of hydrocarbons. Those who lack access to reserves, such as Japan and South Korea, have built energy systems focused on non-hydrocarbon sources of energy and increased efficiency. Reassessments of hydrocarbon positions may radically shift – as in the case of the US and its recently discovered shale gas reserves – or reduce optionality – as in the case of the United Kingdom due to North Sea field decline.

Water availability: The entire energy cycle requires water, from drilling to generation to distribution of energy. Today, energy uses about 8% of all freshwater withdrawn worldwide. In the US, energy now accounts for 40% of all freshwater withdrawals. US Department of Energy officials have therefore told the US Congress that future energy production will be dependent on water access.[3]

Legacy infrastructure: The longevity of energy infrastructure – from power plants to building stock – prolongs the operation of obsolete technologies. Today, light water reactors (LWRs) dominate the nuclear power industry despite being considered inferior to other technologies, particularly in terms of safety. Their dominance is due to 1950s R&D funding by the US Navy, which required the rapid development of a compact and lightweight reactor. As the civilian nuclear industry began to develop, LWRs were at a more advanced stage of development than either heavy water reactors or gas graphite reactors, and came to be the standard design.[4]

Human capital: The energy industry is challenged by a lack of a next generation of employees. Without a significant increase in upskilling and recruitment, the industry will struggle to expand and take advantage of wider technical developments. For example, in upstream oil and gas, the average age of employees is 46-49. With an industry typical retirement age of 55, a severe shortage of human capital is forecast in the near future.[5] The burgeoning renewables industry is growing rapidly and is drawing employees from a small pool of experience, not supported by an established base in education and training. A survey revealed that globally 55% of renewable energy firms had struggled to source talent.[6]



2 EEA Technical Report: Europe's Onshore and Offshore Wind Potential. 2009. Copenhagen: European Environment Agency (EEA).
3 World Economic Forum Water Initiative. Water Security: The Water-Food-Energy-Climate Nexus. 2011. London: Island Press.
4 Cowan, Robin. Nuclear Power Reactors: A Study in Technology Lock-in. In The Journal of Economic History, 1990, Vol. 50, No. 3: 541-567.
5 Ryder, John. Complex Human Resource Challenges Call for New Approaches. In Talent & Technology, 2007, Vol. 1, No. 1: 14-16.
6 Renewable Energy at the Crossroads: Building an HR Structure for Sustainable Growth, 2010. New York: Towers Watson.

A platform approach to understanding and managing the energy risks across the land-water-energy-climate nexus

Juan Carlos Castilla-Rubio, Chief Executive Officer, Planetary Skin Institute

Wes Frye, Chief Development Officer (Energy), Planetary Skin Institute

The Challenge: With the world's population passing seven billion people, resource scarcity becomes the "new normal" for the 21st century. The importance of considering boundary constraints to energy and all resource planning cannot be overemphasized. Managing the complex interrelationships (the "nexus") between energy, water, air quality, land, food and climate is critical to optimize economic growth, accessible energy and environmental sustainability.

There is a fundamental relationship between water, energy and emissions. Coal, gas and nuclear power plants use large quantities of water for cooling steam back into water. Some renewable generation uses large quantities of water as evaporation in hydro reservoirs, irrigation of ethanol-producing crops and steam in solar thermal. Pumping equipment for water treatment and distribution (from cities to irrigation) depends on reliable, low-cost energy.

Water shortages impact energy supply. Droughts have caused temporary closings of nuclear plants in Australia, France, Germany, Romania and Spain. With 88% of its electricity from hydropower, Brazil experienced a severe drought a few years back, forcing the government to ration power to prevent extensive blackouts and cut industrial usage from 15% to 25% at great economic cost. In India, demand for water and energy are projected to double in the next two decades, threatening future energy supply and infrastructure investment.

Water shortages constrain new power plant siting and approvals. In California, the Solar Millennium company was forced to abandon wet cooling for a proposed solar trough power plant after the water district refused to supply the 815 million gallons of water a year the project would need. Conversely, water surplus provides opportunities. Despite being the third largest exporter of oil with vast oil and gas reserves, Norway generates over 99% of its electricity from hydropower.

Most observers can sense that resource constraint issues are imminent, but only rudimentary insights exist on when and where problems are likely to occur and under what circumstances. Many analytic approaches to resource planning exist, but most are economic-focused, static, and span broad regional or national levels. They lack detailed geospatial and temporal resolution needed to perform dynamic risk modelling. This lack of resolution is troublesome for making plans in relation to resources that are local in nature such as water, land and wind/solar/geothermal availability. Yet, this is precisely what is needed to make across-the-board resource allocation decisions that minimize the overall risk profile.

The Opportunity: Assessing opportunities and risks of the energy-water nexus require a more comprehensive approach to resource planning – one that integrates better sensing and analytic modelling capabilities, spans multiple disciplines across various spatial and temporal dimensions (e.g. weather, hydrology, land-use, energy and climate systems), optimizes trade-offs between economic, risk and environment goals, and characterizes information in terms of risk distributions and mitigation measures.

The Planetary Skin Institute was founded to address these capabilities, with innovations to incorporate real-time data feeds from river gauge sensors, machine learning to improve characterization of hydrological models, and continuously update water and energy risk assessments as new socioeconomic and biophysical data are identified. This would better equip stakeholders to answer such important questions as:

- What is the risk probability/impact of energy-on-water and water-on-energy for a specific geography?
- What is the best trade-off between energy-water usage that maximizes overall societal value?
- What scenarios and interventions most reduce the risks on planned energy infrastructure?

Energy planners, industry, government and society-at-large need to adopt a broad, systemic view of how to understand and proactively manage the risks across the land-water-energy-climate nexus. Failure to act will impact our future significantly.

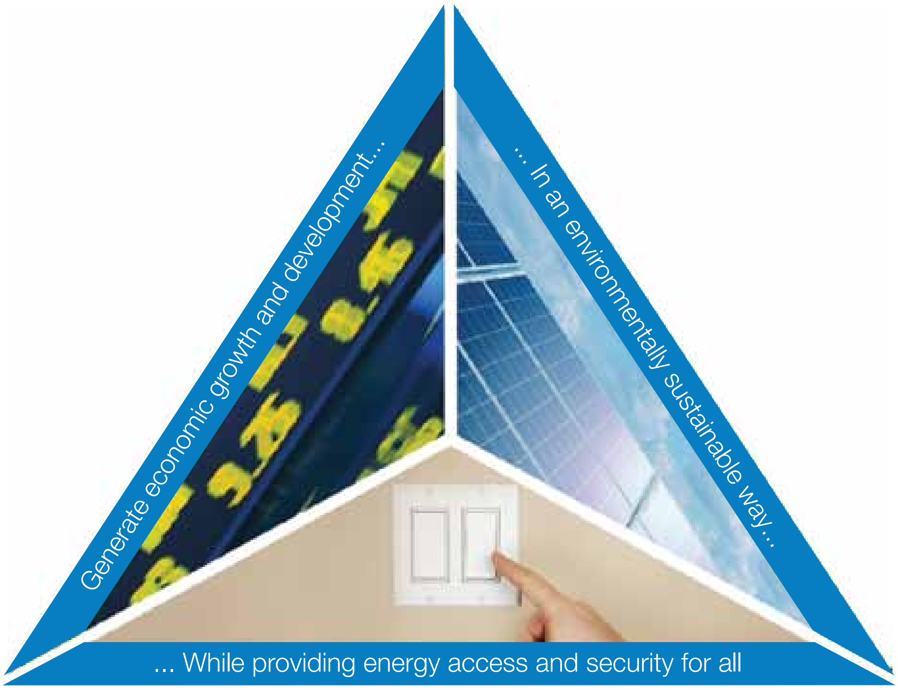
1.2 The Energy Triangle and the Need for a New Energy Architecture

As highlighted above, energy architecture should be designed to meet the imperatives of the energy triangle. We define the purpose of energy architecture more explicitly as being to:

Generate economic growth and development…

Energy architecture underpins economic growth, and is a principal platform for human development and social welfare. It is interlinked with other aspects of critical infrastructure and provides an essential input into many economic processes. The affordability of energy for private consumers and the impact of energy costs on business competitiveness are major issues. Pricing is central to sending appropriate signals to consumers to reflect the true costs of energy and to producers to ensure a viable, responsive energy industry that invests in exploration, production, transformation and distribution.

Figure 2 – The energy triangle



…in an environmentally sustainable way…

The production, transformation and consumption of energy are associated with significant negative environmental externalities. Global attention is currently focused on climate change, with growing scientific evidence suggesting that failure to limit global warming to an increase of 2°C above pre-industrial levels would make it difficult to avoid potentially irreversible changes to the earth's ability to sustain human development.[7] A range of further issues relating to environmental degradation and the energy sector remain of continuing concern, including water scarcity and air pollution.

…while providing energy access and security for all

The secure supply of energy is subject to a number of risks and disruptions. Principal concerns relate to the reliability of networks for transmitting and distributing energy, and the vulnerability to interruptions of supply, particularly for countries unduly dependent on a limited range of sources. Energy security is also about relations among nations, how they interact with one another, and how energy impacts their overall national security.[8] Here we extend that definition to include the provision of adequate access to all parts of the population, in recognition of the importance of tackling energy poverty in many nations in the developing world.

The need for a New Energy Architecture: The growing challenge of the energy triangle[9]

Today, meeting the imperatives of the energy triangle has become particularly challenging as security and environmental imperatives – including tackling resource scarcity and climate change – are both strong, and must be delivered against the background of difficult economic conditions following the global financial crisis.

The financial crisis reminded the world of the intrinsic link between energy and the economy. The International Energy Agency (IEA) has highlighted the important role that the run-up in oil prices from 2003 to mid-2008 played in the global economic downturn[10] and there is a range of literature documenting the connection between hikes in oil prices and the recession.[11]

In the resultant downturn there has been a pressing need for affordable energy to drive recovery through economic growth. Oil prices of around US$ 100/bbl are weighing down on the fragile macroeconomic and financial situation in the OECD, pressuring national budgets in non-OECD countries and encouraging price increases in other commodities.

As economic concerns have grown over the course of the past year, the pressing need to solve the global economic situation has taken priority over discussions relating to environmental sustainability.[12] With rising national debt prompting budget cuts in many countries, some governments are questioning whether they can continue to fund the clean technology programmes and financial support mechanisms that have helped foster innovation in this field. For example, the severe impact of the economic downturn on Spain led the government to retroactively reduce the feed-in-tariff for solar PV by 30% to enable the government some "leeway" in keeping energy prices at a moderate level.

7 IPCC Fourth Assessment Report: Climate Change. 2007. Geneva: IPCC.
8 See Daniel Yergin, The Quest: Energy, Security and the Remaking of the Modern World, 2011, pp. 265-283.
9 The below two sections refer to scenario-based projections of how energy architecture may change. Given that the assumptions that underpin scenarios are often radically different, we have therefore tried to be consistent in the scenario that we refer to, focusing on the IEA's World Energy Outlook 2011 New Policies Scenario.

10 World Energy Outlook 2009. Paris: International Energy Agency. For a more detailed analysis of the contribution of oil price rises to the economic downturn see James Hamilton, Causes and Consequences of the Oil Shock of 2007-08, Brookings Papers on Economic Activity, Spring 2009.
11 Murphy, David J. and Charles A. S. Hall. Energy Return on Investment, Peak Oil, and the End of Economic Growth. In Ecological Economics Reviews. Robert Costanza, Karin Limburg & Ida Kubiszewski, Eds. Ann. N. Y. Acad. Sci. 1219: 52-72.
12 The World Economic Forum's Global Agenda Council on New Energy Architecture highlighted this point at their meeting in Abu Dhabi, United Arab Emirates, in October 2011.

While many countries have moved forward with their plans to address climate change, more needs to be done if we are to meet a scenario in which the increase in global temperature rises is kept below 2°C, as per the Copenhagen Accord. According to the IEA's New Policies Scenario, more than 60% of the global increase in energy use from 2009 to 2035 is expected to be met through fossil fuels, with coal accounting for 20% of the increase.[13] By 2035, the resulting carbon emissions would lead to a concentration of carbon in the atmosphere of 650 ppm CO2 eq., significantly higher than that which international negotiations are currently struggling to achieve (450 ppm CO2 eq.).[14] Today, people worldwide are affected by adaptation challenges such as water shortages, crop failures, tropical diseases, flooding and extreme weather events. The World Health Organization (WHO) estimates that climate change may already be causing more than 150,000 deaths a year.[15] Based on current trends the affects of climate change are likely to worsen.

Despite significant progress, particularly among OECD nations, air pollution remains a considerable, and in some cases, growing challenge for many nations. The expansion in coal use for power generation in countries such as India and China has resulted in continuing high levels of sulphur dioxide emissions. Levels of nitrogen oxides have also grown, and are expected to rise further, as the scale of increasing mobility has outpaced the effect of emissions standards. According to the International Institute for Applied Systems Analysis, these trends imply a worsening health impact. In India, for example, it would lead to a reduction of life expectancy of more than six months per person by 2035, compared with current levels.[16]

Expectations for increasing emissions and concerns over air pollution under current policy scenarios are also a consequence of rising demand. In the next 40 years the global population is expected to increase by one-third, peaking at over 9 billion. This growing population will become an increasingly urban one: the urban population is expected to increase by 85% from 3.4 billion in 2009 to 6.3 billion in 2050.[17] This will result in an explosive growth in demand, with the IEA forecasting a 40% increase in primary energy demand by 2035 in comparison with 2009.[18]

Concerns over energy security are set against a continuing struggle by many nations to even provide access to "modern" energy. Today, 1.3 billion people lack access to electricity and 2.7 billion people are without clean cooking facilities with this figure expected to decline by only 281 million by 2030.[19] Access to modern forms of energy is viewed as being crucial to the achievement of the eight Millennium Development Goals (MDGs)[20] and is intrinsically linked to increasing productivity and promoting economic growth in the developing world.

13 World Energy Outlook 2011. New Policies Scenario. Paris: International Energy Agency.
14 World Energy Outlook 2011. New Policies Scenario. Paris: International Energy Agency.
15 Climate and Health Fact Sheet, World Health Organization, 2005, http://www.who.int/globalchange/news/fsclimandhealth/en/index.html.
16 Emissions of Air Pollutants for the World Energy Outlook 2011 Energy Scenarios. September, 2011. Austria: IIASA.
17 The UN World Urbanization Prospects, 2009 Revision
18 World Energy Outlook 2011, New Policies Scenario. Paris: International Energy Agency.
19 World Energy Outlook 2011. Paris: International Energy Agency
20 See IPCC, Working Group III – Mitigation of Climate Change, Special Report on Renewable Energy Sources and Climate Change Mitigation, 2011, Technical Summary

1.3 The Transition to a New Energy Architecture: What Will the World Look Like in 2035?

National and international attempts to respond to this growing set of challenges are resulting in changes to energy architecture, prompting the transition to a New Energy Architecture.

On one level, this transition represents a shift from carbon-based fuels to non-carbon based fuels, as the world looks to combat climate change. As part of this push two sources will play an increasing role in the energy mix: wind and solar. Wind energy output is forecast to grow from 273 TWh in 2009 to 2,703 TWh in 2035, while concentrated solar power and solar photovoltaic output is expected to increase from negligible output in 2006 to 1,048 TWh in 2035.[21]

The growth in renewable energy, combined with efforts to expand the use of electric vehicles, will result in increased electrification of the energy sector. Electricity generation will account for 18% of total primary energy demand in 2035, up from 14% in 2009.[22]

New technologies are being developed to manage what will become an increasingly complex grid. The top 10 countries for smart grid investment were expected to invest a collective US$ 18.5 billion in 2011[23], and installed smart meters are expected to reach 1 billion in 2016.[24]

21 World Energy Outlook 2011, New Policies Scenario. Paris: International Energy Agency.
22 Energy Outlook 2011, New Policies Scenario. Paris: International Energy Agency.
23 GE Reports: Top 10 countries for smart grid investment, 2010.
24 GE Reports: Top 10 countries for smart grid investment, 2010; Pike research, Smart meter market forecasts, 2011.

The transition will bring a greater focus on natural gas, as hydrocarbons continue to be the mainstay of the energy mix. Under the IEA's New Policies Scenario, hydrocarbons account for 75% of global primary energy supply in 2035, down from 81% in 2009. Even under the IEA's most aggressive carbon abatement scenario, hydrocarbons account for 62% of the mix. The replacement of coal and oil with gas is seen in all scenarios, particularly low-carbon scenarios, with its contribution to global consumption rising from 25% in 2009 to 35% in 2035 in the IEA's 450 Scenario.[25]

Innovation will be seen across the oil and gas sector, as the industry looks to secure sustainable supplies. Deepwater will go deeper, into water depths in excess of 2,000 meters, and into pre/sub-salt as seen in the Lower Tertiary plays in the Gulf of Mexico and in pre-salt Brazil. Fields that exhibit high pressure, temperature, sulphur and CO2 will become increasingly common. Production will also increasingly focus on unconventional assets. Indeed, shale gas production has already been dubbed the "biggest energy innovation in a decade" – tight oil may be the next such innovation.

Clean coal with have a prominent role to play. It accounted for nearly half of the increase in global energy use over the past decade, and, unless aggressive climate legislation is put in place, it will continue to remain the second largest primary fuel globally and the backbone of electricity generation out to 2035.[27] Given its environmental impact, coal's continued use will require an increased focus on increasing efficiency and reducing emissions from coal-fired plants. Change is already underway: in the US low NOx burners were installed on 75% of coal power plants in 2006, reducing NOx emissions by 40-70%, as part of the US Department of Energy's Clean Coal Technology Program [28]; and there are currently14 pilot carbon capture and sequestration (CCS) projects under construction or operating.[29]

There will be a significant role for the "fifth fuel" – energy efficiency – as we transition to a less energy intensive world. Energy intensity is forecast to accelerate its rate of decrease from 1% (1990-2010) to 2% per annum in 2010-2030.[30] Present improvements are partially driven by government intervention. The Chinese government has laid out its 12th Five-Year Plan in which it stated aims to reduce energy intensity by 16% by 2015. Future efficiency improvements will be increasingly driven by cost pressures, as has already been observed in some markets – between 1980 and 2010 the average efficiency of gasoline fuelled passenger cars in America rose by 22%[31] as the nominal price of gasoline increased by 32% (2005 US$).[32]

Finally, the New Energy Architecture will increasingly be one driven by the developing world. Nearly 90% of global energy demand growth out to 2035 is in non-OECD countries; OPEC oil production reaches more than half of the world total in 2035; and non-OECD countries account for more than 70% of global gas production.[33]

1.4 The Effect of Trade-offs on the Transition to a New Energy Architecture

Managing the transition to a New Energy Architecture is not easy. The imperatives of the energy triangle may reinforce or act in tension with one another, forcing difficult trade-offs to be made (see Figure 3).

In some instances, continuing concerns over volatility in the global economy have absorbed significant efforts of government and industry, and have taken precedence over issues connected to environmental sustainability. For example, in September 2011 the US administration backtracked on a new rule to mitigate air pollution. The Ozone National Ambient Air Quality Standard as proposed by the Environmental Protection Agency (EPA) would have reduced ambient ozone, a toxic gas created by power-plant emissions and exhaust fumes. According to the EPA, this would have saved up to 12,000 lives and 2.5 million working and school days lost to the toxic effect of ozone on American lungs each year. The rule would have cost polluters and the government up to US$ 90 billion per year.[34] This toll came to be seen to be too much to levy in a strained and uncertain economic climate.

In other cases, efforts to bolster energy security, such as through the exploitation of unconventional oil and gas reserves, have resulted in growing environmental sustainability concerns. The rapid growth in shale gas production has stoked environmental controversy and policy debate. Some have supported shale gas production in order to boost energy security, as seen in the US where the share of shale gas in produced natural gas rose from 1.6 percent in 1996 to 23 percent in 2010 and is expected to reach 46 percent by 2035.[35] Others have pulled back over environmental concerns, as seen in France's decision to ban hydraulic fracturing, despite a technically recoverable shale gas resource of 180 trillion cubic feet, which dwarfs current proved reserves of 0.2 trillion cubic feet.[36]

In a number of non-OECD countries, the continued use of fossil fuel subsidies as a means to promote economic development has created a market distortion that encourages wasteful consumption, which in many cases heightens existing energy security challenges. For example, in India the government regulates the price of diesel, in order to insulate the domestic economy from the volatility of the international prices of petroleum products. This policy is designed to enable economic development and protect industries such as the haulage sector by alleviating inflationary pressures. However, it has helped contribute to surging demand and increased reliance on energy imports. It also comes at considerable cost; subsidies on petroleum products accounted for 2% of GDP in May 2011.[37] Reforming such

25 World Energy Outlook 2011, New Policies Scenarios. Paris: International Energy Agency.
26 Yergin, Daniel and Robert Ineson, America's Natural Gas Revolution. In The Wall Street Journal, 2 November 2009.
27 World Energy Outlook 2011, New Policies Scenario. Paris: International Energy Agency.
28 Advanced Nitrogen Oxide R&D, US Department of Energy, 2006.
29 Global Status of CCS. 2011. Canberra: Global CCS Institute.
30 BP Energy Outlook 2030, 2011. London: BP.
31 Accenture analysis of Bureau of Transportation Statistics.
32 Accenture analysis of US Energy Information Administration data.
33 World Energy Outlook 2011, New Policies Scenario. Paris: International Energy Agency
34 Supplement to the Regulatory Impact Analysis for Ozone. January, 2010. Washington DC: Environmental Protection Agency.
35 World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States. April, 2011. Washington DC: US Energy Information Agency.
36 World Shale Gas Resources: An Initial Assessment of 14 Regions Outside the United States. April, 2011. Washington DC: US Energy Information Agency.
37 OECD Economic Surveys: India, June, 2011. Paris: OECD.

measures is challenging – the short-term economic impacts on some segments of society are high and induce strong political opposition – but in the case of India, would help an energy sector already creaking under the pressure of high demand.

In some instances trade-offs are not consciously made, with decisions, particularly when taken quickly, leading to unintended consequences. Germany's response to the Fukushima nuclear plant disaster in Japan is one such example. This resulted in the immediate shutdown of Germany's seven oldest nuclear plants, plus the Krummel plant, which has been out of operation since 2009 due to safety concerns. The country's remaining nine plants are to be phased out by 2022, instead of 2036 as previously planned. The decision came alongside a renewed commitment to renewables, which are targeted to account for 35% of electricity generation by 2020, and was intended to bring Germany long-term economic and environmental benefits by putting it at the forefront of green technology. However, in the short-term at least, the economic and environmental impacts may be negative. E.ON announced in August 2011 that it would cut 11,000 jobs, as charges relating to plant closures and the continuing tax on spent nuclear fuel rods, pushed the group to its first quarterly loss in 10 years.[38] Meanwhile the BDI (Bundesverband der Deuschen Industrie) has warned of "certain" electricity price increases for industry.[39] Carbon emissions will also rise, with an increase of between 170 million and 400 million tonnes of carbon dioxide between 2011 and 2020, as Germany turns to coal and gas plants to replace nuclear generation in the short term.[40]

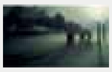
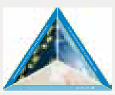
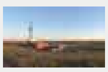
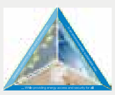
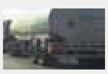
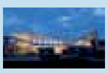
Bringing Balance to the Energy Triangle

What these decisions show is that responses to trade-offs within the energy triangle are prone to change based on the broader macroeconomic climate (as seen in the American decision regarding air pollution) and public sentiment (as can be seen in the German government's response to Fukushima). Of concern is that these decisions are consequently made without detailed analysis, or a consideration of the impact across the energy triangle. Such decisions place the energy system in flux, creating considerable uncertainty for industry and investors.

To bring greater balance to the energy triangle and enable an effective transition, it is important that policy-makers look to the long term, providing a more stable policy environment based upon an in-depth understanding of the trade-offs they are making. Where possible, decision-makers should aim to take actions that result in positive net benefits for all three imperatives of the energy triangle.

Examples of how this can be achieved are discussed in the below set of opinion pieces. Rhonda I. Zygocki, Executive Vice-President of Policy and Planning, Chevron, looks at how a large, long-term energy project can successfully negotiate the expectations and challenges inherent in global energy architecture. Arthur Hanna, Managing Director, Energy Industry, Accenture, highlights the role of energy efficiency (also see Figure 3). Gao Jifan, Chief Executive Officer, Trina Solar, looks at the potential contribution of renewables when given appropriate scale. Fred Krupp, President, Environmental Defense Fund, looks at how shale gas can play a role when appropriate safety measures are put in place.

Figure 3 – Example trade-offs within the energy triangle

Decision		Trade-off	Impact: Economic growth & development	Impact: Energy access & security	Impact: Environmental sustainability
US air pollution regulation 	In September 2011 the US decided not to introduce the Ozone National Ambient Air Quality Standard as proposed by the EPA, which would have reduced ambient ozone		⇧ The rule would have cost up to US$ 90 billion per year ⇧ The rule could have resulted in up to 7 million job losses before 2020		⇩ The EPA estimated that the rule would have saved up to 12,000 lives per year lost due to the effect of toxic ozone on American lungs each year
French shale gas exploration 	In June 2011 the French government banned the use of hydraulic fracturing citing environmental concerns			⇩ France is 98% reliant on gas imports ⇩ Initial exploration indicates that there are technically recoverable resources of 180 trillion cubic feet, sufficient to provide France with gas for 100 years at current consumption levels	⇧ Removal of any environmental concerns associated with hydraulic fracturing, i.e. water contamination
Indian diesel and kerosene subsidies 	In 2010 the Indian government cut the subsidy on gasoline but maintained diesel and kerosene subsidies citing their importance to the transport sector and low-income households		⇧ Removal of the subsidy may have caused increased inflation ⇧ Removal of the subsidy would have further delayed efforts to transition away from using biomass for cooking	⇩ Energy import dependence is now around 25% ⇩ Oil companies remain victims of under-recovery, reducing investment available for domestic exploration	
Energy efficiency in Japan 	In 1998 Japan initiated the Top Runner Program to develop "the world's best energy-efficient products". It set minimum energy efficiency standards based on best in class performance for 9 products, eventually expanding to 21		⇧ Energy efficiency of high consumption products has improved by up to 80% ⇧ Japan has the highest national energy efficiency in the world	⇧ Japan has improved its efficiency by 37% since the 1970s	⇧ Greenhouse gas emissions from transport have decreased

Sources: Shale Gas and New Petrochemical Investment: Benefits for the Economy, Jobs and US Manufacturing, American Chemistry Council, March 2011; EIA, US Natural Gas Imports & Exports: 2010; Life cycle greenhouse gas emissions of Marcellus shale gas, Mohan Jian, W Michael Griffin, Chris Hendrickson, Paulina Jaramillo, Jeanne VanBriesen and Aranya Venkatesh, Environmental Research Letters, July – September 2011; IEEE, Water and Shale Gas Feature, William Sweet, 2010; EU European Energy Portal, Eurozone Fuel Prices, June 2011; European Nuclear Society; The German Renewable Energy Federation – BEE; MAPI, Economic Implications of EPA's Proposed Ozone Standard, Donald Norman, 2011.

38 "German nuclear shutdown forces E.ON to cut 11,000 staff". The Guardian. 10 August 2011.
39 ""Business attacks Berlin nuclear rethink". Financial Times. 30 May 2011.
40 "The knock-on effects of Germany's nuclear phase-out". Nature. 3 June 2011.

Balancing the energy triangle: The Gorgon Project

Rhonda I. Zygocki, Executive Vice-President of Policy and Planning, Chevron Corporation, USA

In an industry as complex as energy, success depends upon making thoughtful and pragmatic choices. Balancing the energy and economic needs of society with the importance of ensuring environmental sustainability can be a challenge, but it is one that Chevron takes very seriously. Providing energy throughout the world requires long-term investments. These investments contribute positively to energy security across many regions and to economic growth and development in many communities. At the same time, safeguarding the unique and sometimes fragile ecosystems that surround operations through sound environmental stewardship is just as important an imperative for Chevron's businesses.

The Gorgon Project off the north-west coast of Australia represents the largest investment in the corporation's history. It also provides an existing model of how Chevron has sought to balance the elements of the energy triangle – economic growth and development, energy security and access, and environmental sustainability – through the development of natural gas.

Strengthening National and Local Economies: At US$ 37 billion (AUS$ 43 billion), the Gorgon Project targets 40 trillion cubic feet of gas and represents Australia's single largest resource project. Estimates indicate that Gorgon will contribute US$ 56 billion (AUS$ 65 billion) to Australia's gross domestic product as liquefied natural gas (LNG) will be offloaded from facilities on neighbouring Barrow Island and transported mostly to Asian markets, while natural gas for Western Australia's consumption will be piped ashore. Australia's prime minister, Julia Gillard, toured the project site recently and said, "Having been here and seen Barrow Island and [the] Gorgon Project, it's given me a real sense of the size and scale of this project and what it is going to mean to the nation's future…This is a great project for employment in this country."

Gorgon's economic benefits will undoubtedly transcend generations and the project is set to be an important pillar of the Australian economy. Throughout its decades-long operational life, it will create thousands of direct and indirect jobs, and the tens of billions spent on local goods and services over the next 30 years will have considerable flow-on effects that cascade throughout the Australian economy. Such is the economic strength of large and long-term energy investments like the Gorgon Project.

Bolstering Security of Supply to Asia and Western Australia: Equally important is the need for energy security. By 2030, world demand for energy is expected to grow by approximately 33%, with Asia predicted to account for 60% of that growth. As demand for energy grows, natural gas will play a vital role to help meet that demand as the cleanest burning fossil fuel. Australia, surrounded by natural gas resources on the doorstep of growing demand in the region, is well positioned to provide much needed supply to a burgeoning part of the world. In addition, diversity of supply is essential for energy security in Australia itself. The Gorgon Project will play an important role in supplying Western Australia's future energy needs by providing a new source of domestic gas. In terms of scale, the roughly 40 trillion cubic feet of natural gas contained in this resource is enough to power a city the size of Singapore for 50 years.

Protecting Biodiversity and Reducing Emissions: Barrow Island, a Class A nature reserve, will be home to the Gorgon Project for many decades. The island's rich and unique biodiversity has remained intact throughout the last 45 years, during which Chevron has implemented stringent quarantine measures, and Barrow's conservation remains a national priority. Maintaining this environmental record involves a mix of advanced technology and a commitment to detail, addressing everything from minimizing the industry footprint to managing light levels from our operations on Barrow's nearby beaches where turtles lay their eggs.

Increasing global demand for energy also requires finding new and improved ways to manage greenhouse gas emissions. Gorgon is playing a leading role with the development of one of the world's largest commercial-scale carbon dioxide injection projects. This process will mean that the project's greenhouse gas emissions can be reduced by about 40%. Moreover, using Gorgon LNG as a form of energy can reduce global greenhouse gases by about 45 million tonnes per annum compared with the use of coal. Put more simply, that is the equivalent of reducing Australia's annual greenhouse gas emissions by 8%.

In these ways, the Gorgon Project represents a current example of how a large, long-term energy project can successfully negotiate the expectations and challenges inherent in the global energy architecture described in this report. Through the safe and reliable production of natural gas, Chevron seeks to provide energy in a way that balances the needs of society. Helping to protect local biodiversity, reduce global emissions, secure energy supplies to sustain human progress in Asia for decades, and deliver long-term economic growth and employment to local and national economies can all be done in tandem, as the Gorgon Project demonstrates.

The Role of Energy Efficiency in Balancing the Energy Triangle

Arthur Hanna, Managing Director, Energy Industry, Accenture, United Kingdom

As highlighted by the World Economic Forum report Energy Efficiency: Accelerating the Agenda, produced in collaboration with Accenture, improved energy efficiency can assist in sustaining economic growth without putting unsustainable burdens on the world's energy supplies or the environment, thereby helping bring balance to the energy triangle. This can be seen in Europe, which the World Energy Council (WEC) highlights as an example of significant improvements in energy efficiency from 1990 to 2006, achieving a 40% average decrease in final energy consumption per unit of GDP. The WEC estimates that if all regions of the world have the same energy efficiency performance as the EU in 2006, a total 420 Mtoe of fuel could have been saved, avoiding 1.3 GT CO2 emissions.[42]

Energy efficiency has now risen to be an important component of energy policies. Over 70% of countries have developed energy efficiency targets[43] and implemented a wide range of policy measures from mandatory targets to incentives and subsidy schemes. China has set a goal of doubling energy efficiency; Russia has set a target of reducing the energy intensity of the Russian economy by 40% by 2020; and in the US the Obama administration has focused on energy efficiency investments as an engine of economic growth: "One of the fastest, easiest and cheapest ways to make our economy stronger and cleaner is to make our economy more efficient."[44]

Energy efficiency savings at the consumer level have a knock-on effect up the value chain. In a traditional coal plant, for example, only about 30-35% of the energy in the coal ends up as electrical output. Although integrated gasification combined cycle (IGCC) plants are capable of efficiency levels above 60%, as are the most efficient gas-fired generators, there is still a tremendous quantity of energy left behind. Meanwhile, transmission and distribution systems, which include everything between a generation plant and an end-use site, typically run at losses of between 6-8%.[45] This means that a unit of electrical energy saved at the consumer level, can result in three units of energy saved upstream.

These energy savings mean more money in the pockets of consumers and an enhanced bottom line for commercial businesses. A study by the Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division into the realized and project impacts of energy efficiency standards for residential and commercial appliances in the US during the period 1988-2006 found that the efficiency gains would lead to US$ 241 billion in consumer savings by 2030.[46] Meanwhile, the Global eSustainability Initiative, a consortium of leading high-tech companies, estimates that smart building technology has the potential to save US$ 20-26 billion in electricity cost savings.[47]

Despite this promise, according to the IEA, improvement rates in overall energy efficiency have declined from a historical average of 2% per year to an average of 1% per year since 1990.[48] Distortions and market failures discourage investment in efficiency. Often, consumers are poorly informed about the savings on offer. Transaction costs are also high: it is a time-consuming chore for someone to identify the best energy-saving equipment, buy it and get it installed. Indeed, energy efficiency is often the casualty of "principal-agent" failures, as in energy-efficient buildings, where developers may be reluctant to take action because the immediate benefit of lower electricity bills will go to tenants not them. Furthermore, consumers' expectations with regard to pay-back periods are often unrealistic, with homeowners demanding exorbitant rates of return on investments in energy efficiency – of around 30%.[49]

Higher consumer demand will be the key growth driver and further work needs to be done on providing a convincing cost perspective to those making investment decisions.[50] Policy-makers should play a role here, providing motivation for consumers to adopt energy efficiency based on a carrot and stick approach, incentivizing energy efficiency through measures such as the UK Renewable Heat Incentive while also mandating energy efficiency standards across the value chain, from vehicles to new buildings and consumer products. These efforts should also be underpinned by the provision of information on the potential benefits of energy efficiency. Policy-makers are not alone in this endeavour. Industry should look to develop new business models as part of an integrated approach to commercial and residential energy efficiency, such as through horizontal integration and the creation of Energy Service Companies (ESCOs).

42 Energy Efficiency Policies around the World: Review and Evaluation. January, 2008. London: World Energy Council.
43 Overview of Energy Efficiency Policies in the World: Synthesis of the WEC-ADEME Survey. June, 2010. London: World Energy Council, www.worldenergy.org/documents/wec_survey_london.ppt.
44 The White House, Office of the Press Secretary, Remarks by the President on energy, 29 June 2009.
45 Energy Efficiency in the Power Grid. 2007. ABB.
46 Meyers, S., McMamon, J. "Realized and projected impacts of US energy efficiency standards for residential and commercial appliances
savings by 2030." The Energy Efficiency Standards Group, March 2008.
47 SMART 2020: Enabling the low carbon economy in the information age. 2008. GeSI.
48 Energy Technology Perspectives 2010 Blue Map Scenario. Paris: International Energy Agency.
49 "The elusive negawatt". The Economist. 8 May 2008.
50 Integrating Energy Efficiency across the Power Sector Value Chain. October, 2011. Geneva: WBCSD.

Renewable Energy's Role in Balancing the Energy Triangle

Gao Jifan, Chairman and Chief Executive Officer, Trina Solar (TSL), People's Republic of China

The energy crisis and climate change are two of the most pressing challenges facing the world today and are set against a difficult economic environment. Mitigating these three challenges – known as the energy triangle – will require significant efforts and financial commitments from stakeholders within both the public and private sectors, as well as civil society. Given appropriate scale, renewable energy has the potential to help balance the energy triangle, contributing towards the creation of a New Energy Architecture.

Despite the challenging economic downturn, the industry has made significant progress toward developing clean energies for the future. In 2010, we saw US$ 250 billion invested in clean energy with the US and Europe adding more renewables than conventional power capacity. As of 2009, China had the world's largest renewable capacity installation; contributing 37 GW to the global total of nearly 80 GW added renewable capacity that year. In addition, we have witnessed the industry moving from laboratory technology to vast commercialized applications in household and large utility scale installation projects such as solar or wind power stations all over the world. Government policies have largely contributed to this surge in investment and production. More nations have recognized the wider benefits of renewable energy and have made the development of renewable energy a top priority. For the first time, China has highlighted environmental protection and energy safety as one of the three main focuses of the 12th Five-Year Plan.

Though the advantages of distributed power generation coupled with the cleanliness and efficiency of manufacturing make renewable energy an optimal solution to meeting the three imperatives of the energy triangle, a significant scaling up of renewables is needed that makes renewable energy economically competitive to other energy sources. In some regions, such as Germany, Italy and California, renewable energy technologies such as solar energy are expected to reach grid parity from the users end in two to three years. Grid parity means the user pays the same amount for electricity coming from solar source as they would from conventional energy sources. With constant innovation by the industry, we are very optimistic that before 2020, the cost of energy produced by renewables would come down significantly to the level that would be as economic as compared to other energy types.

Innovation has also played a key role in the growth of the renewables. In China, the China State Key Lab of Photovoltaic Science & Technology incubated by the private sector is a case in point as an innovative way to drive green growth further. Traditionally, State Key Labs in China are built in universities or state-owned research institutions that receive funding from the central government. The fact that the country approved a state key lab to be built by the private sector sends a positive signal to encourage industry sector to invest and innovate and achieve technological breakthroughs further.

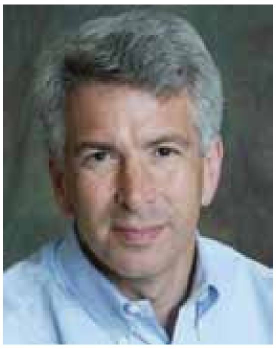
The renewable energy industry by nature comes with an important social responsibility and the industry as a whole is contributing to the community across the world and within their individual organizations. In collaboration with NGOs and charity organizations of all levels worldwide, the industry is donating solar panels or renewable energy solutions and services to people in need and developing off-grid systems for the areas without grid. Through several different education programmes, we are demonstrating to the younger generation the benefits of green energy and they are disseminating that information to the global population.

Looking at the challenge, renewable energy still constitutes a small base in the total energy consumption worldwide, we see a huge gap and also an enormous opportunity ahead of us. Ensuring that renewable energy is available at the lowest possible cost as early as possible and is part of the solutions to energy crisis and climate change, thereby helping to effectively balance the energy triangle is our common goal.

Making renewable energy a main stream in the decades to come cannot be done by one stakeholder alone. What is clear is that each stakeholder has a critical role to play and the scale of challenge will require momentous commitment by all stakeholders across the board. We, as the industry, in collaboration with other stakeholders, are ready to lead the way.

Finding the Right Balance on Natural Gas

Fred Krupp, President, Environmental Defense Fund, USA



As newly abundant shale gas transforms the US energy economy – burgeoning from 2% of total US natural gas supply in 2001 to about 30% today – environmental concerns have overtaken the public debate. People across the US worry that shale gas cannot be tapped without polluting their drinking water, fouling their air and overwhelming their communities. A significant segment of the public has concluded that of the three imperatives of the energy triangle – growth, sustainability and security – the environmental challenge is not being met.

As a result, communities around the US are having a shale gas rethink. From New York to Pennsylvania to Colorado to Texas, cities and counties are enacting rules to regulate, limit and sometimes block development. As the shale gas revolution moves around the globe, with significant reserves identified in China, Argentina, Poland and Mexico, opposition is also spreading. France, for example, has imposed a nationwide ban on hydraulic fracturing.

It does not have to be this way. And the irony is that environmentalists such as myself had cheered the prospect of a shale gas revolution precisely because of the environmental benefit it offered. Since natural gas releases less carbon dioxide when burned than coal, it gives us a short-term way to reduce the emissions that cause global climate change. As we work to shut down our dirtiest coal-fired power plants, demand for natural gas will increase, until the day when truly clean energy sources such as wind and solar achieve industrial scale.

Some are concerned that shale gas will slow the transition to wind and solar. While these concerns are understandable, since the need to accelerate this transition is so great, the truth is that until we develop cost-effective systems for large-scale energy storage, natural-gas fired power will help us deal with the intermittency of wind and solar. Shale gas is a complement to renewable energy, but efforts to make it safe are no substitute for a sensible climate and energy policy. Though natural gas can be an important piece of a cleaner future reaping its benefits requires us to reduce local environmental threats and allay public concerns about impacts to air, water and lands.

Last spring, at the direction of President Obama, US Energy Secretary Stephen Chu created a seven-member natural gas advisory board, charged with recommending ways to ensure that this resource can be tapped safely. I was privileged to serve on this panel, chaired by MIT professor John Deutch, which held a series of hearings, visited well sites and convened a public meeting in southern Pennsylvania to hear directly from people living with intensive shale gas development. While no government panel by itself can restore public trust, I believe our recommendations – if put into place by state and federal regulators and the industry – could help lead the way forward.

The panel's two reports, released in August and November 2011, are a call to action, stating unequivocally that "Americans deserve assurance that the full economic, environmental and energy security benefits of shale gas development will be realized without sacrificing public health, environmental protection or safety...This means that resources dedicated to oversight of the industry must be sufficient to do the job".

I have no doubt that smart, muscular regulation is essential to re-establishing public trust, and I am pleased that the panel endorsed this conclusion.

Industry's failure to disclose the chemicals used to fracture shale formations is one reason trust has eroded. The panel emphasized the need for comprehensive fracking chemical disclosure rules, as well as new standards for well construction and wastewater management. The industry must also provide more data on operations, including emissions of methane, a highly potent greenhouse gas. Methane leakage in the production and distribution of natural gas undermines its climate advantage over other fossil fuels. The panel called for better data collection on leaks and tough standards to reduce these emissions.

The report also calls for the assessment of baseline water quality, disclosure of the composition of drilling wastewater and measurement of air emissions. It calls for a national database of public information on shale gas operations and an industry-led organization dedicated to improvement of best practices.

It is not easy to balance public safety and energy security, but it is essential. Despite the anger and mistrust surrounding the shale gas issue, industry leaders and environmentalists are already working together on the guidelines needed to ensure a safe shale-gas revival. The Environmental Defense Fund, where I work, is collaborating with Southwestern Energy and others to draft model regulations for well integrity that can be tailored to the specific needs and circumstances of each state.

This model regulatory framework, together with implementation of the committee's recommendations, has the potential to change the atmosphere around US shale gas development, but only if industry, environmentalists, and regulators work together. After a year of acrimony, it is high time we did more of that.

Section 2:
The New Energy Architecture Methodology – Enabling an Effective Transition

This project was initiated to help decision-makers enable a more effective transition to a New Energy Architecture. To do so we have created a methodology to help them look to the long term and provide a stable policy environment, based upon a holistic and in-depth understanding of the consequences of decisions across the energy value chain. The end result will be a New Energy Architecture that is more responsive to balancing the imperatives of the energy triangle. This process comes in four steps:

Step 1 – Assessing current energy architecture performance: This process begins with an assessment of current energy architecture performance using a selection of quantitative indicators. These indicators are designed to explore how countries are currently performing in relation to the three elements of the energy triangle.

Step 2 – Creating New Energy Architecture objectives: Based on strengths and weaknesses identified, a set of objectives for a New Energy Architecture that more effectively meets the imperatives of the energy triangle are created.

Step 3 – Defining the enabling environment: An enabling environment that supports New Energy Architecture objectives is designed.

Step 4 – Defining areas of leadership: The ultimate output is the creation of an action plan that details the relative roles of government, industry and civil society in creating an enabling environment for the transition.

Figure 4 – New Energy Architecture methodology

	1. Assessing current energy architecture performance	2. Creating New Energy Architecture objectives	3. Defining the enabling environment	4. Defining areas of leadership
	The Energy Architecture Performance Index	An archetype approach	The four pillars of an enabling environment	Key considerations for stakeholders
Key question	• How is energy architecture currently performing?	• What are the objectives for a New Energy Architecture?	• What enabling environment will achieve transition objectives?	• Who is responsible for implementing enabling environments?
Activity	a) Understand current energy architecture b) Select KPIs to assess current and historic performance	a) Highlight energy architecture challenges b) Identify New Energy Architecture objectives	a) Create an enabler "toolkit" that highlights the potential actions that can be taken to accelerate the transition b) Map enablers to transition objectives	a) Develop high-level action plan for steps to be taken by government, industry, the finance community and civil society to shape the transition

In the following sections we apply this methodology at the global level, while also highlighting some country specific insights. This begins with an overview of the approach taken to assess current energy architecture performance and present the key findings of the analysis. We then explore how New Energy Architecture objectives can be created using an archetype approach. This is followed by an exploration of the enabling environments that need to be created to achieve objectives, which is given further context through deep-dive country studies on Japan and India. The final section discusses the roles of government, industry and civil society in working collaboratively to create an enabling environment.

2.1 Assessing Current Energy Architecture Performance: The Energy Architecture Performance Index

To assess a country's current performance in balancing the imperatives of the energy triangle, we have created an Energy Architecture Performance Index.[51] Measurement and reporting of these indicators is intended to provide a transparent insight into current challenges and a basis from which to make policy and investment decisions, and prioritize opportunities for improvement.[52] The index covers 124 nations, enabling countries to benchmark performance in comparison to their peers. Furthermore, the collection of historic data from 1990, and 1999 to 2008, provides independent analysis of progress over time.

The EAPI consists of three sub-indices that explore each imperative of the energy triangle, providing countries with a means by which to better understand the consequences of their decisions across the energy triangle, and the trade-offs they are making. As highlighted in the below opinion piece from the IEA, taking such a holistic, systems-based approach to managing energy architecture change is pivotal to enabling an effective transition.

The index is structured as follows (see Figure 5):

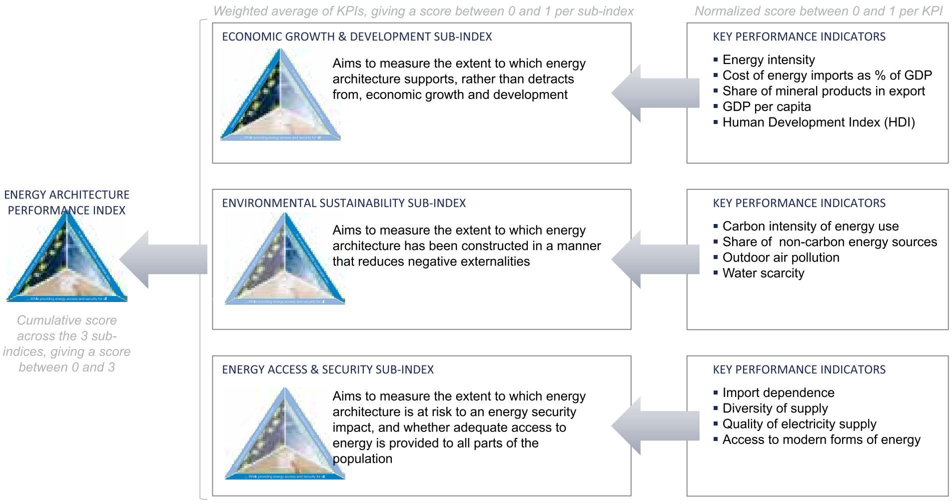
– Economic growth and development (sub-index 1): This sub-index aims to measure the extent to which energy architecture supports, rather than detracts from, economic growth and development. It is measured through 5 variables: energy intensity, as measured by the amount of energy used to generate a unit of GDP; the cost of energy imports, which assesses the extent to which the energy sector has a negative impact on growth; the share of mineral products in export, which assesses the extent to which the energy sector detracts from macroeconomic stability and diversification; and, a combination of GDP per capita and HDI, which have been shown to correlate well with per capita energy use, with a certain amount of energy required to guarantee an acceptable standard of living (42 GJ per capita).[53] Energy intensity is given a higher weighting than the other KPIs within this sub-index as it is seen as being of fundamental importance to assessing the performance of energy architecture,[54] lowering costs and directly boosting productivity by virtue of making better use of inputs.

– Environmental sustainability (sub-index 2): This sub-index aims to measure the extent to which energy architecture has been constructed in a manner that reduces negative environmental externalities. It is measured through four variables: the carbon intensity of energy use at the national level, which measures the emissions of CO2 from the consumption and flaring of fossil fuels; the share of non-carbon energy sources in the energy mix, which indicates the extent to which energy architecture has been designed to limit impact on the environment; levels of outdoor air pollution, as measured by particulate matter concentrations in the atmosphere; and water scarcity, which considers the degree of oversubscription of a country's water supply.

– Energy access and security (sub-index 3): This sub-index aims to measure the extent to which energy architecture is at risk to an energy security impact, and whether adequate access to energy is provided to all parts of the population. It is measured through four variables: import dependence, which indicates the vulnerability of energy architecture to a physical interruption of imports and price spikes; diversity of supply, which indicates whether steps have been taken to reduce supply risk through diversification; the quality of electricity supply, based on a lack of interruptions and lack of voltage fluctuations; and access to modern forms of energy, based on the proportion of the population using solid fuels. It should be highlighted that there are a number of challenges associated with measuring the energy security of an individual nation, since the vulnerability of a state is dependent on the level of integration of its network with neighbouring countries and global markets.

A detailed overview of the computation and structure of the EAPI is provided in Appendix A. Technical notes for the indicators used and details of sources are included in Appendix B. A comparative overview of the results of the index is provided in Appendix C. An analysis of the robustness of the index is provided in Appendix D.

Figure 5 – Energy Architecture Performance Index framework



51 A wide range of literature has been reviewed in conducting research to create these indicators, including Accenture, Accenture Multi-Polar World Index 2010: A new compass for high-performance businesses, 2010; Afgan et al, Multi-criteria sustainability assessment – A tool for evaluation of new energy system, Thermal Science, 11 (3), pp. 233-271; Brent and Kruger, Systems analyses and the sustainable transfer of renewable technologies: A focus on remote areas of Africa, Renewable Energy, 34 (7), pp. 1774-1781, 2009; Carrera and Mack, Sustainability assessment of energy technologies via social indicators: Results of a survey among European energy experts, Energy Policy, 38 (2), pp. 1030-1039, 2010; European Commission, Joint Research Centre, Energy Security Indicators, 2010; Evans et al, Assessment of sustainability indicators for renewable energy technologies, Renewable and Sustainable Energy Reviews, 13 (5), pp.1082-1088, 2009; IAEA, Energy Indicators for Sustainable Development: Guidelines and Methodologies (IAEA, Vienna, 2005); IMF Working Paper, Measuring Energy Security: Trends in the diversification of oil and natural gas supplies, 2011; IPCC, Special report on renewable energy sources and climate change mitigation: Renewable energy in the context of sustainable development, 2011; Lehr, More Baskets? Renewable Energy and Energy Security, GWS Discussion Paper 2009/8; World Economic Forum, Global Competitiveness Index, 2010/11.
52 While quantitative analysis is needed to make decisions that are as informed as possible, it is dangerous to rely on it entirely. The use of indicators is surrounded by a wide range of conceptual and technical issues. For example, often no data is available for a relevant set of measures, while the use of proxies in some instances may convey a message of false accuracy. In using the indicators we have been cognizant of their limitations, and recognize that they may have to be adjusted as new challenges emerge and new data becomes available. Nonetheless we believe that they provide a solid basis by which to assess current architecture performance.
53 IPCC, Working Group III – Mitigation of Climate Change, Special Report on Renewable Energy Sources and Climate Change Mitigation, 2011, Technical Summary, p.127.
54 Both the project Steering Board and Task Force stressed the centrality of energy intensity to any assessment of energy architecture performance, arguing that this should become a greater focus of international benchmarking.

As with any nascent area of research further work needs to be done to expand the robustness and coverage of the index. While much of the data collected for the purposes of this study was freely available and readily accessible, our initial work has shown that some of the data required for measuring key concepts is not yet available:

- Prices: As we enter another phase of the global economic downturn, the affordability of energy is perhaps more important than ever. It is difficult to obtain an index of energy prices to the end user that goes beyond OECD nations. While global data is available on gasoline and diesel prices, this data does not take into account the use of subsidies, which drive economic inefficiencies. A greater understanding of the comparative prices of energy provision will not only assist governments in monitoring and improving performance, but also assist businesses looking to make investment decisions.

- Water: In 2003, the Food and Agriculture Organization of the United Nations published a comprehensive update of its water use estimates in the AQUASTAT dataset, and it has continued to provide new and updated numbers. This data was used for the purposes of this study. However, the year 2000 represented the only year in which there was sufficient data available to conduct a comparative assessment. Furthermore this data is collected using a variety of different approaches, including actual measures, estimations and modelling. Work therefore needs to be done to systematically reassess and standardize national water-use data.

- Energy access: Data on the use of solid fuels is understandably difficult to obtain, given the need to rely on village-level surveys, and other time-consuming statistical techniques. Given the human cost of energy access the continued collection of relevant high-quality data is of vital importance, if this issue is to be effectively monitored.

We recognize that the effort to fully capture the imperatives of the energy triangle through reliable indicators that can be gathered for a large number of countries will require a multi-year effort. At this early stage of development we therefore encourage feedback that can serve as input for further refining and developing the concept.

Key findings of the Energy Architecture Performance Index[55]

There is clear evidence of the transition to a more efficient energy architecture. Improvements in the economic growth and development sub-index have been underpinned by significant advances with regard to energy intensity. This can be seen across countries at different stages of economic development. The US score on this indicator has risen from 0.57 to 0.69 between 1999 and 2008. Much of this has been achieved through real efficiency gains due to greater ingenuity across the energy value chain. China's score on this indicator jumped from 0.12 to 0.29 from 1999 to 2008 due to significant improvements in the efficiency of its energy and industrial sectors. However, looking at the granularity of change reveals a different pattern. For the first two decades of economic reform, China was becoming increasingly energy efficient. However, at the beginning of this century, as it went into high gear as the workshop of the world and its industries went into overtime to supply global markets, it became less efficient, resulting in stagnation in progress between 2001 and 2005. It is only in recent years that efficiency improvements have kicked into high gear again due to comprehensive energy efficiency measures that aimed to improve energy intensity by 20% as part of the 2005-2010 11th Five-Year Plan. A 19.1% reduction in energy efficiency was achieved[56] through measures, including economic incentives and technical strategies to improve efficiency across industry, mandatory energy efficiency schemes for the biggest firms in nine industrial sectors, the closure of legacy and inefficient factories and plants, and the introduction of an appliance labelling scheme.[57]

55 Unless otherwise stated the analysis in this section is based on the results of the EAPI. A comprehensive list of the sources used to compile the EAPI can be found in Appendix B.
56 Seligsohn, D. "The Transformation of China's Energy System: Challenges and Opportunities". World Resources Institute, April 2011.

Evidence of the transition to a low-carbon energy architecture is less promising. While there is evidence of progress on the environmental sustainability index, as the world seeks to transition to a low-carbon energy architecture, much more needs to be done. For 36 of the countries on the index the share of non-carbon sources in total primary energy supply (TPES) is above 10%, 19 of which have a share of 20% or higher. These countries remain the exception rather than the rule. For 69 countries on the index the share of non-carbon energy in TPES is less than 5%. Indeed, of those that do exhibit relatively low-carbon energy architecture, much of this is driven by large nuclear generation capacity, which itself faces a number of sustainability challenges, more prominent since Fukushima. Overall progress has been slow. Only 15 countries show a change in the share of non-carbon sources in TPES of over 5% between 1990 and 2008. Forty-two countries actually exhibited a decline over this time frame.

The slow pace of change is reflected in reductions in carbon emissions. Ninety-six countries show a decline in carbon intensity between 1990 and 2008, but these reductions have been relatively minor. For many nations much of this decline was a consequence of the economic crisis, which temporarily slowed the growth of greenhouse gas emissions, without fundamentally changing their trajectory.

This is not to say that achievements with regard to environmental sustainability should be underplayed; much has been achieved. Indeed, since 1990 all countries on the index, with the exception of two, have reduced outdoor air pollution, caused by nitrogen and sulphur oxides, as a consequence of policies such as the Large Combustion Plant Directive in Europe, which expanded the use of flue gas de-sulphurization. This shows that progress can be made when targeted policies and technical innovations are put in place. Action should be taken on both these fronts to further the transition to a low-carbon energy architecture.

Import dependence is growing, but is being combated by growing supply diversity. For the majority of non-exporting nations, energy imports have grown, as energy demand as a whole has risen due to economic growth. On average, the import dependence of the net importers on the index has risen from 47% to 49%. This has been particularly severe for countries that are experiencing rapid growth, such as India whose import dependence has risen to 25% in 2008, up from 8% in 1990. The economic burden of these imports has also increased. India now spends 10% of its GDP on mineral imports, as compared to 2% in 1990.

Those countries that are exporters of energy, such as Russia and Kazakhstan, have benefited from this trend; as competition from consuming countries has increased, so has the demand for resources. The growth in import dependence has also created new energy exporting countries as exploration activity has risen in response to increased demand. The global rig count has risen by almost 80% since 2000, natural gas exports from Australia have more than doubled since 2000[59] and vast discoveries of oil and gas have been discovered in Ghana, which exported its first oil in 2011. Exceptions to this rule include nations who have historically been energy exporters, but whose production is beginning to plateau, such as the United Kingdom.

Increases in imports have been offset by a more diverse energy mix in many countries. For example, although Spain's energy mix is still dominated by oil, between 1995 and 2010 energy from renewable sources more than doubled to 11% and use of gas increased by a factor of 3-24% while the contribution of coal declined from 24% to 8%.[60]

57 Assessment of China's Energy-Saving and Emission-Reduction Accomplishments and Opportunities during the 11th Five-Year Plan. April 2010. Ernesto Orlando Lawrence Berkeley National Laboratory.
58 Baker Hughes Global Rig Count, http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm.
59 Australian Energy Resource Assessment, 2010.
60 Accenture analysis of data from Secretaría de Estado de la Energía and Recent trends and outlook of the Spanish energy system, European Review of Energy Markets, G Memeth, L Szabo, J C Ciscar and A Soria, 2009.

Top performers on economic growth and development have been able to focus more on environmental sustainability. The index suggests that those countries that are strong performers in terms of economic growth and development have been able to focus more on environmental sustainability, with a significant correlation existing between the two indices. Those who score well in terms of GDP and levels of human development are more likely to exhibit less carbon intense energy use, have lower levels of air pollution and have a higher share of non-carbon energy sources in their energy mixes. This suggests that as countries reach certain levels of economic development, and have reduced pressure on bringing members of the population out of economic hardship, they are able to focus on other factors that contribute to the well-being of citizens.

Petro-states continue to struggle to maximize the value of their indigenous assets in a sustainable manner that supports economic diversification. Those countries on the index that are net exporters of energy are, perhaps unsurprisingly, unlikely to perform well on the environmental sustainability sub-index, and, in particular, are likely to have high levels of air pollution due to the extraction and use of hydrocarbons. Indeed, of all the KPIs used import dependence exhibits the strongest negative correlation with the environmental sustainability index score.

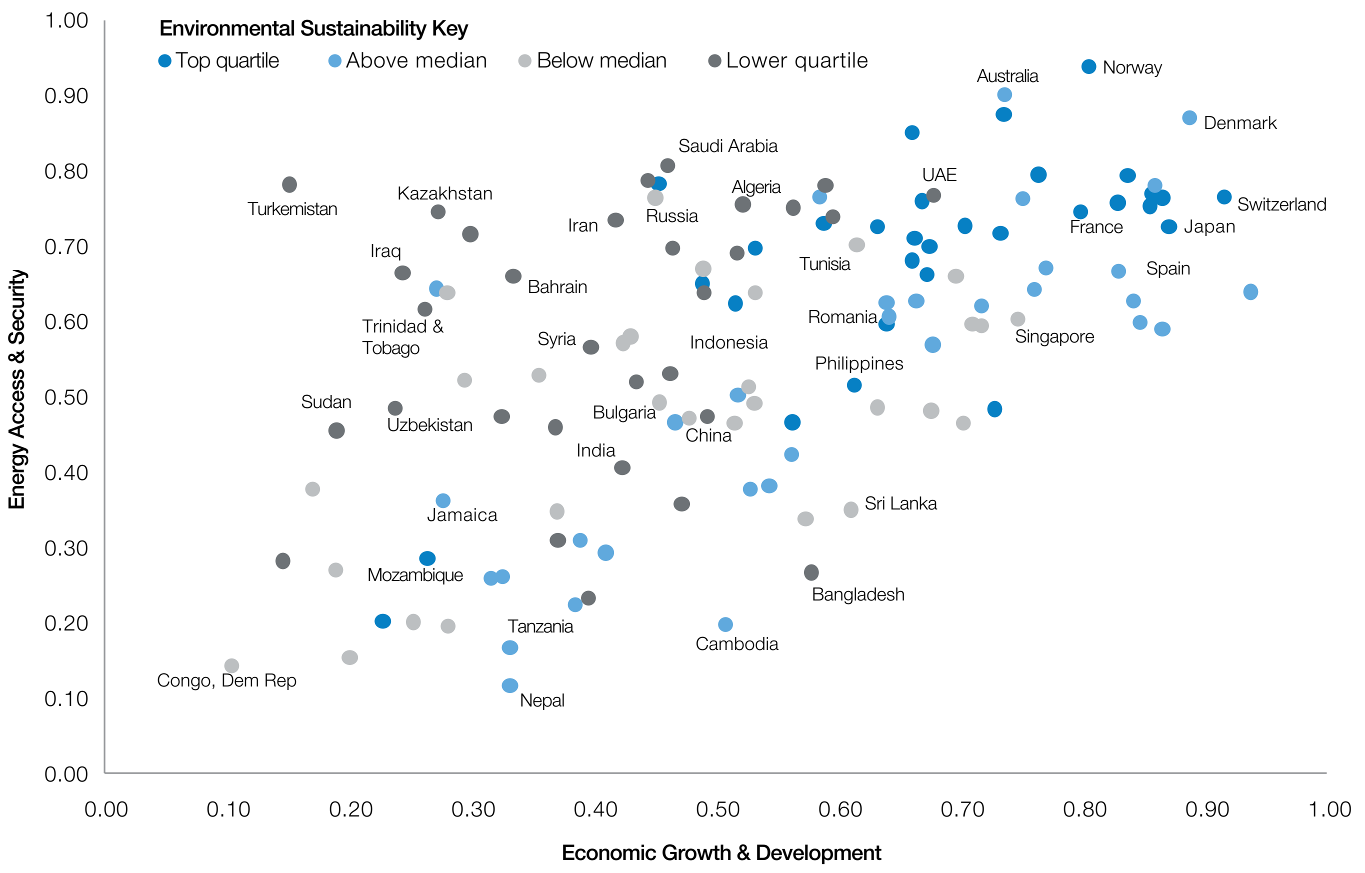
The results of the index also suggest that these countries are struggling to diversify their economies. For this group of nations raw mineral products contribute towards a very high share of exports. For 31 of the 46 net energy exporters on the index over 50% of exports are attributed to mineral products, and for 17 of those countries mineral products account for over 80% of their exports. The majority of these countries have also not been fully able to maximize the benefits of their indigenous resources for the benefit of their populations: most are categorized as having either medium or low levels of human development.

Countries in the developing world are currently focused on optimizing for economic growth and development. The results of the index suggest that many countries have placed a greater focus on optimizing their energy architecture for economic growth and development. Scores for this sub-index have seen greater progress over time. This can be seen particularly in relation to developing nations such as China, India and Indonesia. This quantitative perspective is also borne out from qualitative insights gathered during a series of regional workshops conducted as part of the New Energy Architecture project. During these sessions participants highlighted that developing nations are currently focused on fuelling growth, and that this is a much more significant concern than ensuring environmental sustainability.[61]

A number of nations continue to struggle to supply citizens with basic energy needs. A group of countries on the index perform particularly badly in terms of energy access and security. This is not only a consequence of high levels of import dependence, but also due to an inability to provide citizens with access to basic energy services. In 31 countries on the index over 50% of the population continues to use solid fuels for cooking purposes. The majority of these countries are in sub-Saharan Africa, as well as parts of South Asia and Central America. Twenty-two countries also receive a score of 3.5 or less out of 7 when assessed on the quality of their electricity supply, indicating unreliable and insufficient supply.

In Figure 6 we provide an overview of the results of the EAPI by country. Results for economic growth and development, and energy security and access are plotted on the x and y axis. Results for environmental sustainability are colour coded. The best performing countries are highlighted in solid blue; the worst performing countries are highlighted in solid grey.

Figure 6 – Overview of Energy Architecture Performance Index results by country



61 Private sessions on New Energy Architecture held at the World Economic Forum's regional events in Africa (South Africa) and Asia (Indonesia), as well as the World Economic Forum's Annual Meeting of the New Champions (People's Republic of China), and the India Economic Summit.

Applying Systems Approaches to Meet Energy Goals

Maria van der Hoeven, Executive Director, International Energy Agency, Paris

Significant technology investments are needed to meet the long-term goal of sustainable, economical and secure energy. Rising population and prosperity trends will inevitably increase energy needs in the coming decades. Such investments will need to be carried out globally, requiring engagement worldwide; they will also have to meet the needs of today while anticipating those of the future. It is clear that we cannot continue to rely on our current energy mix. Determining the right balance to ensure security and sustainability will require a systems-level approach.

Current discussions and decisions about the future energy mix require looking to our energy needs, production, and transmission and distribution in the coming decades. Investments and policy actions taken in the short term should avoid "locking in" technologies already known to be unsustainable, particularly those investments with a service life of several decades.

Our energy infrastructure is not based on a single technology, carrier or sector. Rather, it is a highly interrelated system with a plethora of technologies, stakeholders, resources and end uses. Technological complexity will only increase in the future with electric vehicles, increased use of electricity in heating, the use of thermal storage to balance variable renewable generation, more sophisticated demand-response, and energy storage in hydrogen for heating, power generation and transportation. We will need to improve our understanding of evolving energy systems and learn to work with new technologies and stakeholders not traditionally involved in the energy sector.

Systems approaches to energy deployment must look to leverage the existing infrastructure in order to optimize new investments. One example is to improve the flexibility of the current electricity system to accommodate an increasing share of variable renewable investments. The typical approach thus far has been to install fossil fuel peak power stations, but more innovative approaches are possible. Efforts to increase the flexibility of existing base-load capacity, as well as to improve regional interconnections and leverage excess flexibility from reservoir hydro-generation, reduce the need for peak plant investment and increase the utilization of existing generation facilities. There is also a large untapped resource on the demand side to be unlocked through increased deployment of smart grids. By considering opportunities throughout the system, cities, regions and countries can choose the best solution to match their specific circumstance and resource endowment, and thus optimize investments.

There is no one-size-fits-all approach with regard to technology deployment in the energy system. It is in this context that the New Energy Architecture project complements the systems-based analyses performed by the IEA. To meet the demands of tomorrow, nations or regions must consider a broad range of issues, taking a systems-level approach that includes resource and technical capabilities in the context of social, regulatory and market aspects.

The IEA is continuing to expand its system-based analysis, providing answers to new concerns arising from today's ever-changing energy context. Will large-scale deployments of variable renewable generation (such as wind and photovoltaics) disrupt the operation of the electricity system? Can the distribution system accommodate future electric vehicle deployments? Should gas networks be expanded for use in building heating applications or should electricity-based heat pumps be used? How can hydrogen technology be deployed in a practical and cost-effective manner for transportation or stationary applications? Will smart grids increase or decrease the cost of electricity to consumers?

Such questions cannot be answered in isolation. Systems thinking must be the rule to allow the energy community, including governments, industry, consumers and all other stakeholders, to work in collaboration globally in an effort to find creative solutions to meet our secure and sustainable energy goals.

2.2 Creating New Energy Architecture Objectives: An Archetype Approach

The results of the Energy Architecture Performance Index (EAPI) must be read in context. Countries both developed and developing are all at different starting points. Contextual differences – such as the structure of each nation's economy and the severity of boundary constraints – mean that the response taken by countries to respond to challenges in their current energy architecture will vary: objectives for a New Energy Architecture will therefore look very different.

To account for such differences, studies on energy transitions often take a regional perspective. However, there is considerable heterogeneity between countries within single regions. In recognition of this we have created a series of archetypes, grouping countries who face similar challenges in their current energy architecture, and who therefore have a similar vision for a New Energy Architecture that is more responsive to the imperatives of the energy triangle:

– Rationalize: Rationalize countries are mature economies that have established energy architectures that strongly support economic growth and development. Their focus is increasingly on rationalizing and re-organizing energy architecture to balance the energy triangle. Key opportunities for these countries are in advancing existing infrastructure, identifying and integrating new sources of supply, and driving greater efficiency across the value chain.

– Capitalize: Capitalize countries have energy architectures that strongly promote security, largely as a consequence of significant hydrocarbon reserves. Their focus is on capitalizing on their resource base over time in a sustainable way. Key opportunities for these countries involve diversification of economies, and leveraging experience to enable expansion across the energy value chain.

– Grow: Grow countries have energy architectures that are focused on securing continued and rapid economic growth. Their focus is on alleviating supply bottlenecks, to reduce supply-demand deficits. Key opportunities for these countries lie in bringing new forms of supply online, delivering it more effectively to consumers, and doing so at a market based price.

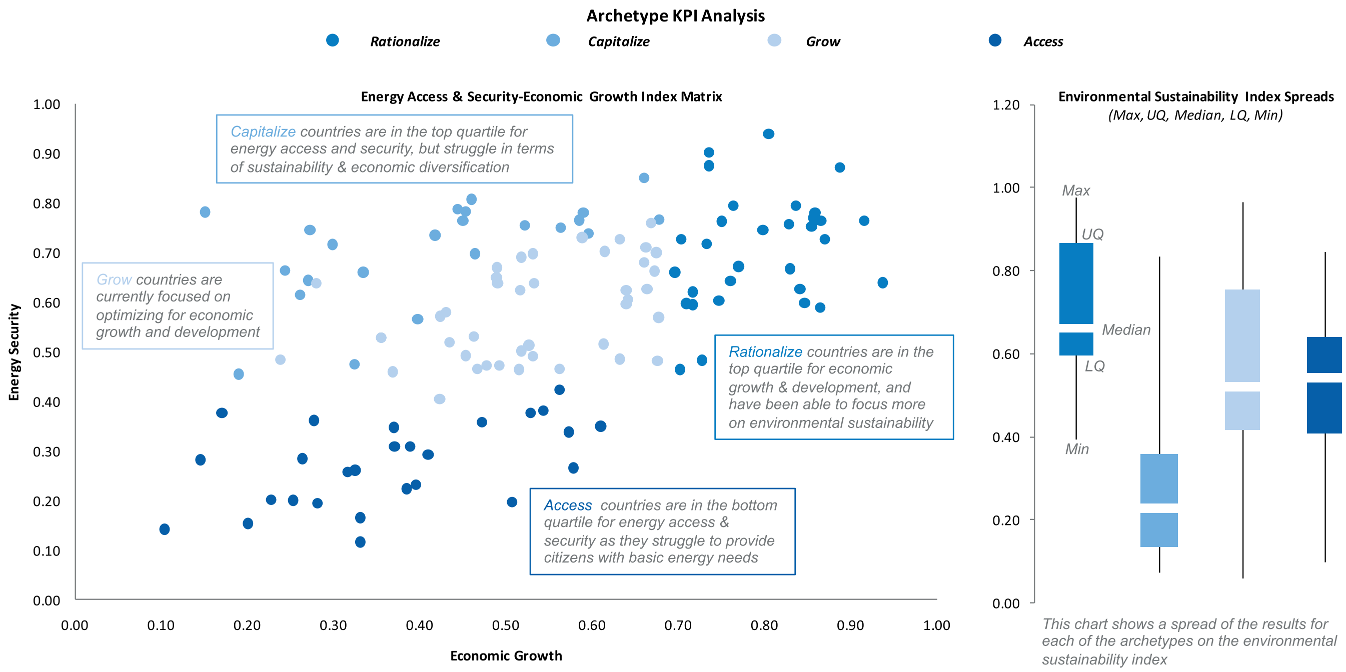
– Access: Access countries have energy architectures that struggle to provide citizens with basic energy needs. Their key focus is on expanding access to modern fuels at an affordable price. Key opportunities for these countries include rural electrification, and reducing the proportion of the population using biomass for cooking and heating purposes.

The archetypes are not exhaustive, but are intended to provide a new framework for thinking about energy transitions – one that recognizes that there is no one-size-fits-all model. Thinking in terms of archetypes also enables nations to compare their performance relative to their peers, and can help create policy competition, where archetypes learn, through diverse national approaches, about the varying costs and benefits of different transition strategies.

Countries were allocated to archetypes based on their performance on the EAPI, as can be seen in Figure 7. Those in the Rationalize archetype scored in the top quartile for economic growth and development. The Capitalize archetype includes those that scored in the top quartile for energy access and security. The Access archetype covers those in the bottom quartile for energy access and security. The Grow archetype covers all remaining nations. In some instances countries exhibit features of more than one archetype. A review of these countries was completed, with countries then allocated to the archetype that represents their most prominent characteristic. Figure 8 provides an overview of the global distribution of the archetypes.

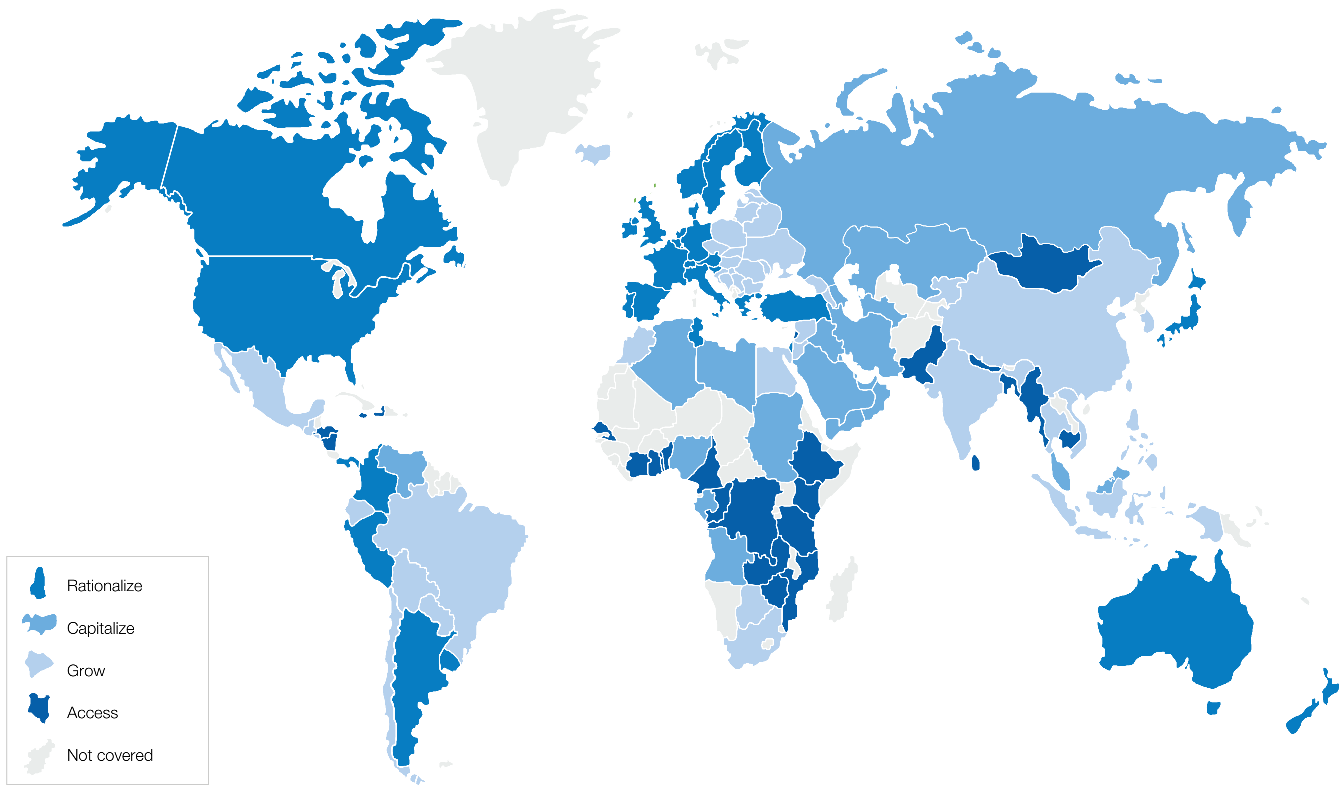
A more detailed overview of each of the archetypes is provided in Figure 9. This includes key characteristics, representative countries, an overview of current energy architecture performance and objectives for a New Energy Architecture. The objectives we highlight indicate what their focus will be out to 2035 in order to bring greater balance to their energy triangle.[62]

Figure 7 – Performance on the Energy Architecture Performance Index by archetype



62 Archetypes and objectives were developed based on input gained from regional meetings of the World Economic Forum, particularly the Annual Meeting of the New Champions, as well as in-country interviews conducted in Japan and India.

Figure 8 – Global distribution of archetypes*



*A number of nations were not covered by the index due to a lack of sufficient data.

Figure 9 – Overview of New Energy Architecture archetypes

Rationalize

Rationalize: Rationalize countries are mature economies that have established energy architectures that strongly support economic growth and development. Their focus is increasingly on rationalizing and re-organizing energy architecture to balance the energy triangle. Key opportunities for these countries are in advancing existing infrastructure, identifying and integrating new sources of supply, and driving greater efficiency across the value chain.

This archetype consists principally of countries within the OECD, whose energy sectors strongly support economic growth and development. Many of these countries have begun to increasingly focus on environmental sustainability, launching a variety of policy initiatives to support this move. They tend to have legacy assets and capital stock that reduce their development options in this regard. Because of demographics, the structure of their economies, and increased efficiency their energy consumption tends to be flat or declining.

Representative countries: Canada, Denmark, France, Germany, Italy, Japan, New Zealand, Sweden, Switzerland, United Kingdom, United States

Current energy architecture performance: Performance is relatively strong across the board, particularly in relation to economic growth and development. Key challenges are in maintaining economic growth and development given recent dips in performance; reducing import dependence; and reducing carbon intensity.

New Energy Architecture objective – Overcome architecture lock-in: Countries within this archetype have the objective of rationalizing their energy sectors by retro-fitting existing infrastructure, such as building in smart technology to transmission and distribution networks, and by identifying and integrating new sources of supply, and by driving greater efficiencies across the value chain.

Potential trade-off: The adoption of new and more sustainable technology is in many cases expensive. A number of technologies on the generation side have not yet reached grid parity, yet initiatives have been launched that strongly support their expansion. This impacts energy prices, and potentially economic growth.

Capitalize

Capitalize: Capitalize countries have energy architectures that strongly promote security, largely as a consequence of significant hydrocarbon reserves. Their focus is on capitalizing on their resource base over time in a sustainable way. Key opportunities for these countries involve diversification of economies, and leveraging experience to enable expansion across the energy value chain.

This archetype consists principally of countries that are exporters of oil and gas, such as those in the Middle East, North Africa and Central Asia. Often referred to as “petro-states” they depend on oil and gas exports to generate economic growth, and to maintain social stability. Their industrial focus often results in a heavy impact on the environment, also a consequence of large subsidies for fossil fuels. They also potentially run the risk of suffering from a range of economic problems, including “Dutch disease”, where oil exports cause inflation harming other industry sectors; capital absorption, where funds are diverted from other investments; and reform fatigue, where structural economic problems are not tackled due to the potential for future wealth. The common challenge for these countries is to ensure that the opportunities for longer term economic development are not lost to economic distortion and the ensuing political and social pathologies.

Representative countries: Azerbaijan, Brunei Darussalam, Colombia, Iraq, Kazakhstan, Kuwait, Oman, Qatar, Russia, Saudi Arabia, United Arab Emirates

Current energy architecture performance: Performance is strong in relation to energy access and security. Key challenges are in regard to reducing reliance on mineral products for export; increasing diversity of supply; and in all areas related to environmental sustainability.

New Energy Architecture objective – Maximize energy industry returns: Countries within this archetype have the objective of capitalizing on the value of their indigenous assets in a sustainable manner that supports economic diversification. This can often be achieved by leveraging their knowledge and understanding of the energy sector and applying it to new and emerging technologies.

Potential trade-off: Options with regard to maximizing energy sector returns are not necessarily sustainable. They must therefore be carefully considered and executed to ensure co-benefits across the energy triangle.

Grow

Grow: Grow countries have energy architectures that are focused on securing continued and rapid economic growth. Their focus is on alleviating supply bottlenecks, to reduce supply-demand deficits. Key opportunities for these countries lie in bringing new forms of supply online, delivering it more effectively to consumers, and doing so at a market based price.

This archetype consists principally of countries that are going through a rapid growth phase, such as those in East Asia and Central and Eastern Europe. They feature growing urban populations, but many also have large rural hinterlands. Due to the growing strain of economic growth, physical infrastructure often falls short of national needs, despite increasing investment. Many of these countries experience peak supply deficits, and regular black-outs. The challenge for these countries is to increase reliability, ensure that power supplies keep up with economic growth, and avoid shortfalls that constrain growth.

Representative countries: Chile, Hungary, India, Indonesia, Korea, Mexico, China, South Africa, Thailand, Turkey, Vietnam

Current energy architecture performance: Performance is average across the indicators. Key challenges are in regard to improving GDP per capita; reducing import dependence; and increasing the share of non-carbon sources in total energy supply.

New Energy Architecture objective – Alleviate supply-demand deficit: Countries within this archetype have the objective of accommodating growing demand by bringing new forms of supply online, delivering it more effectively to consumers (both urban and rural), and doing so at a market based price (based upon the eventual eradication of subsidies where present).

Potential trade-off: Attempts to reduce supply-demand deficits run the risk of impacting environmental sustainability if not completed efficiently. Countries should look to initiatives that help decouple economic growth from energy use.

Access

Access: Access countries have energy architectures that struggle to provide citizens with basic energy needs. Their key focus is on expanding access to modern fuels at an affordable price. Key opportunities for these countries include rural electrification, and reducing the proportion of the population using biomass for cooking and heating purposes.

This archetype consists principally of countries in Sub-Saharan Africa, and in parts of South Asia and Central America. They feature large rural populations, which are dispersed, difficult to reach, have low electricity consumption needs and low capacity to pay. Countries face a dual choice between grid extension and stand-alone systems. Often institutional structures or regulatory frameworks need to be introduced or strengthened to encourage investors or the private sector to participate in electrification and cookstove schemes.

Representative countries: Bangladesh, Benin, Cambodia, Ethiopia, Ghana, Haiti, Kenya, Mongolia, Nepal, Tanzania, Togo

Current energy architecture performance: Performance is strong on environmental sustainability due to low energy use. Key challenges are in regard to driving economic growth and quality of life; providing citizens with basic energy needs; and water scarcity.

New Energy Architecture objective – Increase access to modern energy sources: Countries within this archetype have the objective of expanding access through rural electrification rates and expand access to modern fuels for domestic and industrial use.

Potential trade-off: Expanding energy access may negatively impact environmental sustainability if not carefully planned. Countries should look to initiatives that bring co-benefits for environmental sustainability.

2.3 Defining the Enabling Environment: The Four Pillars

Figure 10 – The four pillars of an enabling environment

The creation of appropriate enabling environments that support the transition is central to achieving New Energy Architecture objectives. An analysis of countries from each of the archetypes that have created strong enabling environments has shown that they consist of four pillars: policy initiatives, to put in place the rules, price signals and risk-return incentives that attract investors and facilitate development; technology and infrastructure to fix specific challenges in a country or stage of the value chain; market structures to allow producers to meet consumers' needs efficiently; and human capacity to drive change and develop solutions.

This analysis has also shown that the four pillars must be deployed in a mutually supportive manner; failure to integrate efforts will likely lead to an inadequate enabling environment that hinders the transition. Success therefore hinges on the involvement of all stakeholders – government, industry and civil society – working together.

In the following section we discuss some examples of best practice in creating enabling environments before detailing the results of deep-dive studies into countries from two archetypes – Japan (Rationalize) and India (Grow) – and suggest the steps they need to take to create an enabling environment.

The four pillars of an enabling environment

Achieving New Energy Architecture objectives is contingent on the creation of an appropriate enabling environment. Enabling environments consist of four pillars:

1. Policy initiatives: Frameworks and incentives should be created to put in place the rules, price signals and risk-return incentives that attract investors and facilitate development. Regulations should be consistent, transparent, evidence-based and include strict standards of governance. A strong policy platform will unlock the potential of business to do what it does best: profitably invest and innovate.

2. Technology and infrastructure: Technological innovations should be deployed to fix specific challenges in a country or stage of the value chain. Technology pilots should be performed in developing countries to take advantage of the lack of legacy technology and infrastructure, strong growth prospects and availability of resources. Government and industry must look to create and align standards to reduce production costs and facilitate integration.

3. Market structures: Market structures should be created to allow producers to meet consumers' needs efficiently. This entails creating market links between players along the value chain, financing mechanisms to reduce risk and appropriate scales of supply and demand.

4. Human capacity: Human capacity should be developed in order to both drive change and develop solutions. To drive change will require increased citizen access to information (e.g. smart metering). To develop solutions will require increased focus on education, training and accreditation by professional bodies to overcome the scarcity of technical knowledge, ability and experience.

Sitting across these four pillars is information. Making changes to energy architecture requires building support from all stakeholders in civil society, including the public at large. The establishment of communication channels between stakeholders is a necessary step towards promoting better understanding of the risks and benefits associated with energy architecture change. The provision of information is therefore central to driving a bottom-up acceptance of, and even pull for, change.

Tools within the four pillars of an enabling environment

In the below section we provide a series of perspectives that look at a selection of examples of the enabling "tools" within each of the four pillars that can be used to enable a more effective transition. These perspectives were developed in association with members of the project steering board and task force, and highlight examples of best practice and innovation from across the energy value chain.

Juergen Arnold, Chief Technology Officer, Enterprise Servers, Storage and Networking, Hewlett-Packard, explores information and communication technology (ICT), and its integral role in ensuring information flows across the four pillars, with a specific example of how this has been applied in the oil and gas sector

Jim Kelly, Global Head of Energy Efficiency, ABB, looks at the tools that the Capitalize archetype can use to reduce their environmental footprint.

Anant Gupta, President, HCL Technologies Infrastructure Services Division, highlights how better grid management can enable a New Energy Architecture.

Gabriel Barta, Head of Technical Coordination, IEC International Electrotechnical Commission, explores the role of standards in ensuring consistency, reliability and assurance across New Energy Architecture, and how this may particularly help the Grow and Access archetypes.

Information and Communication Technology (ICT) – Key Enabler for the Transformation

Juergen Arnold, Chief Technology Officer, Enterprise Servers, Storage and Networking, Hewlett-Packard

Energy is the lifeblood of modern society, essential to our health, safety and prosperity. Growing demand, volatile economies, limited supplies and aging infrastructures are increasing unpredictability. Governments are mandating more open and competitive markets, requiring new smart grid technology to conserve energy, and demanding more reliable security of supply. There is an increased pressure to reduce the massive energy carbon footprint and provide more renewable sources for energy. Technology modernization is opening the door for intelligent grids backed by new world information systems that enable more information exchange than ever before. An increasing move to de-regulated competitive markets and the introduction of new players are placing new customer management demands on established companies. In response to these extreme market conditions, energy related companies are moving beyond optimizing operations to transforming them.

Organizations can use five key "levers" to execute their plans and make the predictive organization a reality:

1. Information management: Information management helps bring information together. To be effective, it should encompass the end-to-end information life cycle, from acquiring data from a variety of sources to delivering information to decision-makers. Effective information management is the key to successfully forging one view of operations, and ensuring that this view is accurate, trusted and ultimately used by all relevant parts of the business. An example of dramatic chance in volume of information is the implementation of smart grids and meters in the utilities industry. From one data point/year today to one data point every 15 minutes or even real time in the future, billions of information sets need to be processed.
2. Advanced analytics: This can help companies monitor assets more closely and stay on top of the high volumes of production data coming from, for example, digital oil fields. It enables them to identify trends, simulate production to find "cause and effect" links between production events, and predict the behaviour of assets.
3. Sensing: The evolution of sensors is moving forward and companies will need to take advantage of this advancing technology to get a more comprehensive and timely perspective on operations. Sensors can provide a broad range of operational measurements, and companies and organizations that deploy more of them will naturally have a better handle on the actual state of their operations. Environmental monitoring enforced by governments is also a huge field for sensor implementation.
4. Cloud computing: As all processes will become digital, huge amounts of data need to be processed and converted into information in a timely and cost efficient way. Sourcing the necessary power and storage requirements from the cloud instantly enables organizations to focus on their core business competence.
5. Security: Energy systems are mission critical infrastructures and need to be protected from unauthorized access and any form of manipulation. Intellectual properties of companies and user data need to be protected at any step in the value chain. ICT has the tools and methodologies to deliver the required security, privacy and data protection enforced by governments.

ICT and transforming seismic imaging

ICT innovations will be used in new ways to help transform the energy sector. For example, ICT is critical for security, safety and environmental monitoring, seismic imaging for oil, gas and geothermal energy, and digitizing the oil and gas production to make oil and gas recovery cleaner, more efficient and lower cost. However, the energy industry and the ICT industry must continue to find new and innovative means of partnering to more quickly and fully utilize ICT technologies against the most challenging energy sector problems.

An example of this type of collaboration exists between Shell and Hewlett-Packard to develop the next generation of onshore seismic imaging technology. Seismic imaging technology is commonly used to map the subsurface during oil and gas exploration and production. However, although the world's energy companies spend US$ 10-20 billion per year on seismic imaging, the image results are often of poor quality, potentially resulting in dry or low-producing wells. The oil and gas industry needs imaging techniques that are better at imaging difficult geologies, and offer higher resolution and higher fidelity at lower cost.

Shell and Hewlett-Packard are collaborating on an extensive multi-year programme to develop a new paradigm in seismic imaging. They are dramatically improving subsurface imaging by increasing the number of sensors on the ground during a survey by an order of magnitude to 1 million, creating a wireless network to deliver real-time control of all of these sensors, and processing over 30 terabytes of data per day in remote field locations. The anticipated result will be dramatically better subsurface images to help in locating oil and gas resources and enhance recovery. Over the next several years, we expect to see more collaboration like this which use ICT knowledge and innovation to address core energy challenges.

Connecting Oil and Gas Platforms to the Mainland Power Grid

Jim Kelly, Global Head of Energy Efficiency, ABB, Switzerland

The transition to a New Energy Architecture will see innovation applied across the whole energy sector. There will be major leaps in innovation that will see the creation of new technologies, companies and sectors. Equally, we will also see significant incremental innovation. As the need to transition to a New Energy Architecture becomes more apparent to stakeholders, they will look for quick wins that will provide better balancing of the energy triangle in the short term and at relatively low cost.

As highlighted by this report, a key challenge for countries within the Capitalize archetype is how to exploit their resource base in a sustainable way; it is likely that technological innovation will be sought to provide solutions. One area which is already beginning to see change is the offshore oil and gas industry, with its ever increasing economic and environmental challenges.

Traditional offshore simple-cycle gas turbine generation has come under mounting scrutiny in recent years due to its inherently poor efficiencies, greenhouse gas emissions and its unfavourable impact on the overall health, safety and environment of platforms.

These externalities can be dramatically altered by connecting the platform's electrical system to the mainland power supply via a subsea cable transmission system. This outsources the task of electrical power generation to the mainland where it can be managed in a centralized, more efficient, cleaner, safer and economically accepted way, unrestricted by the tighter space and weight limitations associated with offshore installations. Energy efficiency can, in many cases, be improved by 50%. This provides a significant reduction in greenhouse gases, as many offshore platforms need power in the range of 50-160 MW. A 100 MW offshore gas power plant can easily generate 500 k tons of CO2 a year over its 30-40 year service life, so lifetimes savings can be substantial.

The power links can be realized by two types of technology: AC powered cables or DC HVDC Light technology. AC cables are employed for smaller power needs and shorter distances. DC cables are more efficient for larger power needs and longer distances. The power from shore concept gives additional benefits such as reduced maintenance, cost reduction, reduces helicopter traffic and high reliability. Annual operating costs are typically lower than those of gas turbines; capital cost varies by project and needs to be evaluated individually. Greenfield and larger re-development projects hold the greatest potential for this approach.

While the use of subsea cable transmission systems should be evaluated on a case by case basis, the use of such large scale CO2 emission reductions can be an effective way for oil and gas producers within the Capitalize archetype, such as Norway where the concept has been successfully implemented to contribute towards the emission target commitments of their international agreements. The power from shore concept is also used in the Middle East. Such projects have already been completed in Saudi Arabia and are under development in Qatar and Abu Dhabi. These are driven by environmental benefits as well as operational effectiveness.

Real Time Grid Optimization: Shaping the New Energy Architecture

Anant Gupta, President, HCL Technologies Infrastructure Services Division, India

Throughout the Energy Industries' history, the electricity distribution network has always been the primary link to the consumer. This direct connection has been overlooked with minimal investment applied to understanding the value that can be delivered through the energy supply chain. Instead, most of the energy industry has focused on new sources of generation and the interstate distribution network required to transmit energy. This highly visible touch point to the customer has significant relevance in terms of security and reliability of energy supply. Whatever the source – renewable, fossil or nuclear – the distribution system is critical in providing an end product to the consumer.

The extensive scope of the distribution network and a utility's ability to monitor and control performance of the network beyond the primary substation has traditionally been restricted. The existing infrastructure and equipment are rated primarily on relatively static projections of loading and peak demands. With the introduction of micro-generation and increased point loads (such as electric vehicle charging) or added demand, maintaining reliability and asset optimization plans will help minimize the cost of needed investments.

In established countries, challenges come with the expansion of micro-generation and increased point loads, such as electric vehicle charging, that pose varying demands on the networks compared to traditional designs. In growth economies, the challenges are directly related to higher loads on networks, creating dangerously overloading and requiring allocation of scarce resources to repair, replace or strengthen the networks, interrupting consistent supplies to the end customer.

Emerging technologies in the smart grid arena provide opportunities to improve system reliability, performance and efficiency of the distribution infrastructure and adapt to these new challenges. The increased availability of new low-cost monitoring devices for the distribution grid can leverage existing metering infrastructures that are already in place and offers the opportunity for utilities with real-time condition monitoring of low-level distribution equipment to analyse data at a micro level rather than at a macro level. Data monitoring via sensors can be placed on a variety of devices to provide the utility with a significant amount of real-time information, allowing grid operators true decision support.

Utilities and network operators now have the opportunity to make better informed decisions regarding circuit and equipment load that are consistent with extending asset life and managing the risks of energy delivery – environmental, safety, outage among others. Improved information on static assets will enable a utility to base decisions for asset replacement and network investment on real-time data rather than projected condition information or the manufacturer estimated lifespan. Most importantly, it provides focused targeting of investment on supply reliability improvements, as well as increasing the potential for energy efficiency through load management at the customer level.

Asset management solutions in today's marketplace do not effectively support real-time, event-based data collection at the micro level. What is needed is a real-time, high performance, asset analytic tool that can turn vast operational data into event driven actionable decisions, which alter asset management strategies and drive higher reliability with true financial benefits. The output of these solutions will actively predict what assets should be invested in the long term, and how the utility will increase overall customer satisfaction through optimizing of the grid with outage avoidance. Real data based design will bypass costly build specifications.

Network operators face conflicting challenges of sustainable investment and distribution network management, ultimately providing reliable supply at the same time facing reduction in revenues from efficient use and innovative new applications of energy. This development will provide real solutions to resolve these conflicts through reduction in expense on existing asset. In the end, operators will apply smarter maintenance and optimized planning to cost effectively extend the investment in their asset base.

Development and deployment of these technologies is aligned with New Energy Architecture objectives. The Rationalize group support maximizing the value of the existing asset base. Grow countries support more efficient allocation of scarce resources to enable more rapid spread of delivery networks to meet the increasing demand.

Consistency, Reliability, Assurance

Gabriel Barta, Head of Technical Coordination, IEC International Electrotechnical Commission, Geneva

The two enabling pillars of policy initiatives and technology, like the transition to New Energy Architectures in general, will be global or they will fail. Not only regional interdependencies but also the need for consistency and reliability will force many technical rules, infrastructure projects and regulations to depend upon wide agreement and a homogeneous approach. There is no one-size-fits-all in energy architecture, but there is and must be a one-size-fits-all definition of the energy efficiency of a particular type of product or installation, for example. Similarly, the interoperability, flexibility and stability of the future electric grid – the characteristics which require it to become "smart" – all depend on a single, agreed set of constraints applying to all connected nodes. Or again, policy incentives for particular investments or behaviours must be based on agreed rules or they will be perceived as unfair and will be inoperative.

The factor common to these examples and many others is *international technical consensus*, the rational agreement of all stakeholders on a single technical rule or specification. The most effective method of reaching such a consensus is the development of International Standards, and the IEC is responsible for all of these in the domain of electricity, electronics and related fields. Once consensus is reached and an International Standard is published, the work has of course merely started. Products and installations must be designed and built in conformity with the standard, their conformity must be checked, and if necessary certificates, marks or other types of information on conformity must be supplied. There are vast numbers of players involved in these activities, but all following a single specification which is the strength of the process.

An agreed specification is needed in many areas touched upon in the present report, and the reader will be able to name others beyond the examples already cited. It is important to be clear, however, on the fact that not all technical characteristics should be standardized. In many areas innovation, freedom and efficiency, as well as commercial success, depend on not having a technical blueprint that all must follow, and the present report also contains many such examples. The clearest is perhaps the imperious need for technological innovation in reducing greenhouse gas emissions, in electricity generation as well as other domains, where it would be counterproductive to prescribe the design and technical characteristics of generating plant beyond those guaranteeing safety and sustainability. At the other end of the scale, many areas of energy architecture need standards early to reassure market players and provide predictability for the long-term return on investments.

International Standards represent a worldwide consensus, not biased by country or region, economic weight or stakeholder type. Regulations relying on such specifications will be visibly fair and comparable across sectors and countries, as well as using the best available know-how (something that historically not all regulations have succeeded in doing). Standards will thus make it easier for governments and industry to carry out their action plans to move towards their New Energy Architecture. The IEC, for example, consists of 163 countries, 81 members with "national electrotechnical committees" and 82 "affiliate countries", and operates around 200 technical committees relying on the efforts of perhaps 10,000 experts in any one year. The experts come from all stakeholders, with a majority from industry and many others from governments, regulators, users and universities.

In addition, for the Access countries and some of the Grow countries, International Standards will form part of the resources they need to develop their New Energy Architecture. Standards can provide them with know-how and steer the creation of infrastructure in ways that advanced-technology countries and multinationals can do or have done whether or not standards existed. Thus, for some countries, standards represent technology transfer and reassurance that the country is investing in the best technology and can serve as catalysts for capacity building.

Independent assurance that products and systems are in conformity with International Standards should be provided through international conformity assessment systems, as conducted by the IEC. Many of the standards applied are relevant to energy efficiency, electric power generation and other indispensable aspects of energy architecture.

The continued success and usefulness of International Standards to the New Energy Architectures depends on the continued involvement of all stakeholders in the development of standards. Readers of the report, interested in a successful transition but not currently involved in international standards, could therefore contribute.

Success in building enabling environments

The four pillars of an enabling environment must be deployed in a mutually supportive manner. For example, the successful deployment of large-scale renewables into energy architecture requires a portfolio of complementary flexible generation, strengthening and extending network infrastructure and interconnections, energy storage technologies, modified institutional arrangements including regulatory and market mechanisms, newly trained technicians to manage the system and public acceptance.

Failure to integrate efforts across the four pillars will lead to an inadequate enabling environment that hinders the transition. For example, India's five-year plans have historically placed emphasis on power generation expansion. However, this results in loading more and more power on an inadequate transmission and distribution network. Since transmission and distribution investments have not kept pace with investments in generation, power cannot be easily moved from surplus to deficit areas. Industrial and commercial establishments have been forced to seek captive and standby generation to meet demand or provide quality supply on a 24/7 basis to support critical processes and provide peaking support. There therefore needs to be a greater alignment between policy initiatives and infrastructure build out.

This is further underlined by an analysis of countries from each of the archetypes that have achieved recent success in creating enabling environments. The countries selected were highlighted during interviews conducted as part of the New Energy Architecture project:

Sweden (Rationalize): Sweden passed its 50% renewable energy generation targets for 2020 in 2010, and has achieved this success by creating a stable and strong policy framework that encourages the energy market to operate efficiently. It has initiated fiscal policy initiatives that help ensure taxation incentivizes the use of renewables in certain industries while not harming overall economic growth. It fully supports the liberalization of the country's energy markets and has played a leading role in the creation of a common Nordic wholesale market for electricity. These innovative ideas are supported by a policy framework that not only encourages large-scale investment in R&D but focuses on reducing the "to market" time of new renewable technologies, therefore reducing dependence on non-renewables and stimulating economic growth.[63] At the same time, the government has supported the creation of competency centres to act as hubs for renewable energy research. The centres not only seek to create useful and potentially profitable new technologies but also develop the knowledge base and human capital required to sustain Sweden's energy policy. Sweden's population is highly environmentally focused; a 2006 survey found that the population believe only education and research, medical and childcare, and unemployment and pensions should receive more funding from the government than the "general environment".[64] This national sentiment has driven the success that Sweden has seen in achieving its environmental targets.

Colombia (Capitalize): Colombia has been able to revive its energy sector over the course of the last decade, as a shift in policy initiatives and market structures prompted international investment, which brought new skills and technologies into the country. Towards the end of the 1990s oil and gas production in Colombia had begun to decline due to a lack of major new discoveries and a deteriorating security environment that made operations more costly. To attract new investment, the regulatory framework was revised; royalties were cut from a flat 20% to a sliding scale of 8-25%; an independent oil and gas regulator, the National Hydrocarbons Agency, was created; and state oil company, Ecopetrol, was partially privatized and made to compete with international firms in new upstream bid rounds. This open-door policy stands in contrast to neighbours such as Venezuela, Bolivia and Ecuador. Indeed, Colombia has benefited from an influx of Venezuelan engineers, experts at dealing with the heavy oil that represents the bulk of Colombia's recent energy finds.[65] In response, investment in the oil and gas sector has increased 10-fold between 2002 and 2010.[66] The influx of capital has brought with it better technology and improved recovery rates in aging fields, helping to boost output. While signs of "Dutch disease" have been observed as the Colombian peso has appreciated, the government is now discussing the creation of an oil stabilization fund to help ease any currency revaluation.

China (Grow): As China's economy started growing rapidly and domestic reserves of oil and gas dwindled in the mid-1990s, the government recognized that securing energy supplies was of strategic national importance. It then began to implement a range of detailed policies and regulation, such as the Golden Sun programme, which encouraged the development of a renewable energy sector through financial subsidies, technology support and market incentives. Today, China is rated as the most attractive market for renewable energy investment and is seen as being in the lead of the "clean energy race".[67] China's grid-connected renewable capacity is 263 GW, with renewables accounting for 18% of electricity generation.[68] This growth has been supported by a strong set of policy initiatives, ranging from renewable portfolio standards, to feed-in-tariffs and one-offs such as 2008's US$ 46 billion "green" stimulus package. Continued political and regulatory support, combined with lower labour and manufacturing costs, have benefited Chinese firms. Of the top 10 wind manufacturers, four are Chinese – Sinovel, Goldwind, United Power and Dongfang – while seven of the world's top 15 solar PV cell manufacturers are Chinese, including Suntech, JA Solar, Yingli Green Energy and Trina Solar.[69] Continued technology development at these firms has resulted in a closing gap in technological parity with overseas firms. Indeed, Chinese firms are now expanding West, as marked by Suntech's establishment of a US manufacturing presence.

63 Energy Policies of IEA Countries – Sweden. 2007. Paris: International Energy Agency.
64 Boman, M., Mattsson, L. A note on attitudes and knowledge concerning environmental issues in Sweden. In Journal of Environmental Management, 2007.
65 "Colombia's oil production is gushing". Los Angeles Times. 12 May 2010.
66 Colombia's Energy Renaissance. December, 2010. The Americas Society/Council of the Americas Energy Action Group.
67 Ernst and Young, Renewable energy country attractiveness indices, August 2011, Issue 30; Pew, Who's winning the clean energy race?: Growth, competition and opportunity in the world's largest economies, 2010
68 Renewables Global Status Report 2011. July, 2011. Paris: REN21.
69 Renewables Global Status Report 2011. July, 2011. Paris: REN21.

Bangladesh (Access): Since independence in 1978, Bangladesh has placed a high priority on rural electrification; between 1998 and 2009 the electrification rate increased from 17% to 41%.[70] In recent years, this trend has increased. In the early 2000s, the Bangladeshi government – through the Rural Electrification Board and international banks and bilateral donors – established a rural energy fund, implemented by the Infrastructure Development Company Limited, which has enabled a group of 30 participating sales and services companies to install some 750,000 solar home systems, most of them 50-75 W. A third of these systems were installed in 2010 alone, and it is estimated that 30,000 solar home systems are now being sold each month.[71] Key to the programme's success have been high-quality system standards and guarantees, combined with after-sales service, and the active participation of microfinance organizations such as Grameen Shakti and BRAC, which have facilitated sales and have guaranteed system quality. Since its inception in 2002, the programme has expanded to include a national biogas initiative, solar micro-grids, solar pump irrigation and biomass-based power. The programme illustrates the benefit of having a dedicated organization to coordinate outreach for renewable energy in rural areas.

Defining enabling environments for the archetypes

The above examples not only indicate that success is contingent on the deployment of the four pillars in a mutually supportive manner; they also show that creating an enabling environment is highly context dependent. The countries highlighted were tackling a variety of challenges; each "success" looked very different as did the enabling environments they used to get there, with a variety of tools employed. This underlines that there is no one-size-fits-all approach to enabling an effective transition to a New Energy Architecture. Enabling environments will be a function of:

- Current energy architecture performance: The condition of existing energy architecture will be an important determinant of the decisions taken to create an enabling environment. This will be based on an understanding of strengths and weaknesses of current energy architecture, using such tools as the Energy Architecture Performance Index.

- New Energy Architecture objectives: The specific objectives that enabling environments are designed to achieve will also vary in each instance, reflective of the archetypes' challenges and ambitions. As has been highlighted, New Energy Architecture objectives range from reducing supply deficits, to providing access to modern forms of energy.

- Consideration of boundary constraints: During the creation of an enabling environment and identification of objectives, there must be an appreciation of the presence or lack of boundary constraints, which may be present in each nation and whether these are fixed or variable

To draw out some of these issues further and explore how the approaches taken within the archetypes differ, we have conducted a series of deep-dive country studies on representative countries from the archetypes. This process began with an assessment of current energy architecture performance using the Energy Architecture Performance Index. This was then validated during a series of in-country interviews and a multistakeholder workshop. These sessions were also used to generate New Energy Architecture objectives, and a set of options for creating an enabling environment that supports the transition. The findings highlighted below are based on the views and opinions expressed by interview and workshop participants.

70 The Electricity Access Database. Paris: International Energy Agency.
71 Renewables Global Status Report 2011. July, 2011. Paris: REN21.

The detailed findings of these country studies are not intended to be representative of all the countries in each archetype; differences naturally emerge at the micro level. However, the broad themes addressed within each of the country studies are common to the relevant archetypes. For example, India's core challenges relate to its need to reduce its supply-demand deficit in a sustainable way, while fuelling growth – a story seen across the Grow archetype. Meanwhile, Japan's principal challenge relates to rationalizing its sizeable capital stock in the energy sector to incorporate new forms of supply, and to drive behavioural change – a challenge seen across the Rationalize archetype. Countries within the archetypes should therefore look to these country studies to identify where they face a common set of challenges, and to see if they too can adapt based on the lessons learned.

> **Japan does not have an energy crisis. It has a crisis of confidence.[72]**

A Deep-dive into the Creation of an Enabling Environment for the Rationalize Archetype: Japan

On Friday 11 March 2011, Japan's north-east coast was hit by a magnitude 9 earthquake, followed by a large tsunami, devastating the region. There were four nuclear power sites with operating reactors in the area affected. The tsunami inundated the Fukushima-1 site where six boiling water reactors were located. As engineers struggled to get the reactors back under control, a series of explosions resulted in the release of radioactivity into the atmosphere.

The Fukushima incident has sparked a broad debate about the direction of Japan's energy architecture in which the general public and many other stakeholders have engaged on an unprecedented scale. It has been evident that the handling of the incident has led to a loss of faith in both the government and the power sector – there is a clear need to restore public confidence. In response, the government is conducting a wholesale review of energy policy that will result in the most significant changes to the sector since the response to oil shocks in the 1970s.

72 Interviewee, Tokyo, Japan, October 2011.

Making the Transition

Before the Fukushima disaster, Japan had planned to generate up to 60% of its electricity from nuclear power by 2050. Worries over the sustainability of nuclear power, as well as increasing concerns about safety and security, have lead the public and policy-makers alike to question Japan's energy policy. It has also made the issue of creating a New Energy Architecture much more prominent; the Japanese government has already responded to the concerns of civil society by committing to reduce dependency on nuclear power and promising to find alternatives to non-renewable sources. However, these transition objectives are not without costs. Decommissioning nuclear power plants is expensive and any rapid change would jeopardize Japan's energy security and increase its dependence on fossil fuel imports. Equally, a major shift towards renewables would require a transition on a scale never seen before and necessitate vast amounts of financial investment.

Japan's focus for the coming years will clearly be on restoring supply and ensuring energy security. In the longer term Japan has the opportunity to drive innovation in its energy architecture, creating a new model that other nations may learn from and adopt. To do so Japan should consider pursuing the following set of objectives:

- Objective 1 – Expand renewable deployment and support the development of "new" energy industries: Japan must look to develop and deploy renewable and "new" energy industries such as storage to decrease dependency on energy imports, diversify supply, reduce emissions, and to create a new export industry to drive economic growth.
- Objective 2 – Rethink approach to nuclear energy: Nuclear energy will continue to play an important role in Japan's energy mix for the foreseeable future; Japan should look to continue R&D in an effort to build a stronger nuclear industry. Fundamental changes to the running and regulation of the nuclear sector to ensure transparency and accountability are required to secure public acceptance.
- Objective 3 – Create new markets and infrastructure for energy transmission and distribution: Restructuring of the transmission and distribution industry is needed to drive increases in economic and technical efficiencies, increase transparency of the sector and enable the deployment of renewable generation capacity.
- Objective 4 – Create a new best practice model for energy efficiency: Demand side management has shown to be effective and responsive to supply shortages in the aftermath of the Fukushima incident. This potential to reduce demand while maintaining economic competitiveness should be leveraged through the introduction of energy efficiency measures.

The Required Enabling Environment

To enable Japan to address its objectives, an enabling environment will be needed. The creation of an enabling environment will require support from across all four pillars:

Government policies must be created to facilitate the deployment of renewables and rebuild faith in nuclear. The government must create a policy framework to encourage the private sector to invest in renewables by providing further clarity on how the feed-in tariff will function. Planning regulations across local, regional and national bodies must be simplified and rationalized to facilitate deployment of renewables. An independent regulatory body for the nuclear industry must be created that regulates and fosters development.

Lack of infrastructure is preventing the deployment of renewable generation. Many of Japan's prime renewable generation sites are not covered by the power grid, thus preventing investment in the industry. In addition, a lack of interconnections between the 10 separate transmission networks is further preventing the deployment of renewables and reducing load levelling opportunities. Japan has one of the lowest Aggregate Technical and Commercial (AT&C) losses globally and a world-class reputation in scientific and engineering excellence; it must look to become the supplier of choice to the Asian markets through continued development and investment in "new" energy technologies.

New market structures can lower prices and increase security. The government should look to create Special Economic Zones in the tsunami affected areas to reinvigorate the economy and develop sustainable technologies. Japan has some of the highest industrial electricity prices in the world and the government needs to perform a cost-benefit analysis into more complete deregulation of the power market. A pan-Asian energy network would bring security of supply to the region and enable improved demand side management. Japan must leverage its technical, economic and political strengths to lead the way in the creation of a regional power market.

Highly skilled scientists and engineers will be required. Japan has been long renowned for its scientific and engineering excellence but a decline in new engineering graduates has been witnessed since the late 1990s. The availability of highly skilled engineers for innovative renewable energy research and other clean technologies such as electric vehicles is low. Opening up international science and engineering education programmes at universities will help to attract new talent.

The provision of information must be clear, transparent and honest. The population has already shown itself to be interested in the nuclear debate and capable of responding to information as seen with the need for energy efficiency in the aftermath of Fukushima. The establishment of clear communication channels will enhance the flow of information, increase trust of the energy sector and drive further change.

To create an enabling environment will require government, industry and civil society to work together. Government must become more transparent and responsive to change, instigating developments in policy and regulation in response to the demands of civil society. Industry must demonstrate that it can innovate and has the capacity and expertise to deliver change to Japan and the wider Asian market. Most importantly, civil society must utilize public sentiment and opinion in a post-Fukushima world to drive the creation of effective policy and fully engage debates over how the future energy architecture will be shaped.

A Deep-dive into the Creation of an Enabling Environment for the Grow archetype: India

"Inability to meet energy demand could be the single biggest constraining factor to India's growth story.[73]"

73 Interviewee, New Delhi, India, October 2011.

The last decade has been a period of tremendous growth for India. This growth has driven a large increase in energy demand, with India now being the fourth largest consumer of energy globally. Between 1990 and 2008 total demand grew by 95%[74] and has put India's energy architecture under severe strain. India has provisionally set a 9% GDP growth target as part of the 12th Five-Year Plan, which will require energy supply to grow 6.5% per year.[75] This represents a much more significant growth target for the sector than in previous years. The focus for the coming years will therefore be on supporting economic growth by providing a secure supply of energy. Indeed, inability to meet energy demand could be the single biggest constraining factor to India's growth story.[76]

India does have a responsibility to achieve its growth trajectory in an environmentally sustainable manner, and has set a voluntary target to cut the emissions intensity of GDP by 20-25% by 2020 compared with 2005 levels.[77] Therefore, the way forward should be to identify common ground between climate change policy and economic growth and pursue measures that achieve both.

Considering that there needs to be a significant expansion in energy infrastructure, India has an opportunity to pursue development while managing emissions growth, enhancing its energy security and creating world-scale clean technology industries. This would require that India leapfrog inefficient technologies, assets and practices and deploy ones that are more efficient and less emission-intensive, with a key opportunity being the expansion of decentralized distribution and generation. India should therefore not look to copy the Western model of energy infrastructure development, and instead pursue a development path that is particular to its local conditions.

Making the Transition

The focus for the coming years will be on supporting economic growth by providing a secure supply of energy. To provide a secure supply of energy and address further issues of distorted energy pricing, poor air quality, growing water scarcity and import dependence, coupled with the unreliability of the grid and continuing energy poverty, requires India to bring new forms of supply online, deliver it more effectively to consumers (both urban and rural), and do so at market-based prices (based upon the gradual phase-out of subsidies).

Objective 1 – Augment resources for energy security: India must look to encourage and expand the presence of international coal as well as oil and gas companies to provide the investment and technical expertise to develop domestic hydrocarbon resources, invest in continuing development of the renewable industry and look to increase efficiency in end use consumption.

Objective 2 – Provide access to modern forms of energy for all: India must promote the role of the private sector in developing and deploying decentralized distribution and generation and modern cookstove and lighting technologies to rural areas where lack of awareness and state-level bureaucracy is impeding progress.

Objective 3 – Strengthening energy carriers: The financial health of transmission and distribution companies must be improved to enable investment in strengthening, expanding and developing the power grid while gas infrastructure must continue to expand its small but growing coverage.

Objective 4 – Rationalize energy prices: To transition to a more efficient economy, India needs a well-instituted market mechanism for energy pricing and must gradually withdraw wide-scale energy subsidies while ensuring that transparent and effective distribution of kerosene and LPG to those below the poverty line is implemented.

The Required Enabling Environment

To enable India to address its objectives, an enabling environment will be needed. The creation of an enabling environment will require support from across all four pillars:

India has a strong policy framework at the national level, but implementation at the state level is often lacking. The public policy regime for the promotion of renewable energy at the national level is viewed as being among the most effective in the world – "a benchmark for all emerging markets".[78] However, success in implementing national targets varies significantly on a state by state basis. Poor performing states should be targeted to promote capacity building and encourage wider economic development.

Development of the power grid is urgently needed. The transmission and distribution network is in urgent need of investment and development and India has the opportunity to leapfrog Western countries through the deployment of more efficient, less intensive and smarter technology. India has seen rapid development in its renewables sector, especially in wind energy. This expertise and momentum must be leveraged and applied to other technologies particularly solar.

Costly and inefficient subsidies are damaging the economy. The energy market must be made more transparent and efficient to attract foreign and private investment. This will require the removal of subsidies and increased separation between the government and state-owned companies. Market structures for the transmission of electricity between states must be rationalized in order to foster the development of renewable generation and better load balancing.

India can become a centre of excellence for renewable energy R&D. India has a large and growing educated population and this must be leveraged to provide the technical skills that will be required to make the transition to a New Energy Architecture. Society must be more aware of the consequences of energy consumption and the role of decentralized distribution and generation in providing modern forms of energy and bringing opportunities for economic development.

The provision of information is essential for the deployment of new technologies. The effective, transparent and sympathetic dissemination of information will be key in developing India's energy architecture, from communicating the removal of subsidies to the need to consume energy more efficiently. Honest and upfront communication will also be essential to gaining the involvement of international and private energy companies in the development of India's hydrocarbon resources.

The government's role in creating a strong, stable and transparent policy framework is essential. This will require strong political leadership to manage the effective removal of subsidies and enable the benefits from increased private sector participation to be fully passed onto the public. India's population is growing in size and wealth and private companies must look to exploit this opportunity. This will involve investing in collaborative partnerships to gain access to technology and skills and deploying new technologies to market. The true cost of energy use and wastage must be communicated by civil society so that changes in subsidy levels and energy architecture are accepted. Cultural changes such as the acceptability of electricity theft must be altered. The role of modern forms of energy in developing the welfare and economy of rural areas must be imparted.

78 Tanti, Tulsi R. "Wind matters: Making the case for wind in India". Suzlon, 2011.

Taking a Global Approach to Creating Enabling Environments

While each nation will need to respond to their own challenges, they must recognize that their actions will have implications at the regional and global level. Nations must also recognize that their ability to change their energy architectures is constrained by the regional and global system.

There is the same requirement to deliver against the imperatives of the energy triangle at the regional and global level, as at the national level. Energy markets across supply sources have become increasingly interconnected via a range of forms of infrastructure, including LNG trade, intercontinental pipelines, regional transmission and distribution networks and so forth. This not only means that trade in energy takes place on a regional and global scale, but also that supply stability increasingly resides in regional and global markets. Equally, the externalities created by energy production and consumption are international and must be addressed at the regional and global level.

At the global level a range of tools can be deployed to create enabling environments to accelerate the transition to a New Energy Architecture that more effectively underpins the imperatives of the energy triangle. These tools range from free trade initiatives for sustainable energy products (to help promote economic growth and development) to the creation of a global framework for emissions reductions (to help promote environmental sustainability), as well as the expansion of the Joint Oil Data Initiative to include natural gas and upstream investment (to promote energy security).

While it is not the mandate of this report to tackle these global solutions, we recognize that no country can act in isolation.

2.4 Defining Areas of Leadership: Key Considerations for Stakeholders

The creation of an enabling environment that is resilient to risk and responsive to the imperatives of the energy triangle goes beyond an individual corporation or government's scope. Three key groups of stakeholders have a role to play: government, industry and civil society. To enable an effective transition these stakeholders have to work together. Coalitions will be required to meet the New Energy Architecture challenge, with each stakeholder group leveraging their own expertise.

The role of the three stakeholders – government, industry and civil society

Government – Creating a stable policy platform: Clear and sustained government policy support is an essential prerequisite for an effective transition. In public and private sessions conducted on the topic of New Energy Architecture at World Economic Forum regional events, it was clear that industry figures and thought leaders from across the energy value chain believe that unstable policy environments continue to remain significant obstacles to change.

Policy-makers must increase short-term decisiveness to provide a more resolute policy environment that encourages development. Recent years have seen a series of policies delayed – such as the UK Renewable Heat Incentive – as governments seem to lack confidence in their decision-making ability.

Policy platforms should not only be stable, they should also not be overly onerous. The task of government is to provide a framework in which markets and industry can act. Excessive bureaucracy should therefore be limited where possible. For example, in Japan, complex planning laws requiring decisions to be approved at the local, regional and national level have impeded the deployment of additional grid infrastructure needed to deploy renewable generation.

Finally, once a clear policy platform has been created, policy-makers should look to support capacity building, including centralized support for R&D programmes and skills development for new and emerging industries. This is particularly relevant for countries such as India, where national mandates are implemented at the state level.

Industry – Driving implementation through innovation and investment: Industry should build on government's lead, driving implementation through innovation. From a technical perspective, industry has already been remarkably successful in accelerating the transition. Across the value chain significant advances have been made, ranging from the 20-year effort by the Mitchell Group and others to develop shale gas production, to the expansion of renewable sources of energy led by rapidly growing firms in emerging markets such as Suzlon and Trina Solar.

Increased levels of inter-industry collaboration will be vital to ensure continued innovation as energy firms look to leverage each other's knowledge and experience, access new markets and gain additional funding for highly capital intensive projects.

Where further innovation is perhaps needed is in creating new business models. There are two areas in which this need is clear: supporting energy efficiency and expanding energy access. For example, an integrated approach to commercial and residential energy efficiency can be achieved through the creation of horizontally integrated energy service companies, and in the access space leasing models can help make solar equipment affordable for low-income consumers and increase ability to pay for renewable energy services, particularly for remote rural communities.

A potential obstacle to industry's role in creating enabling environments to support the transition is human capacity. In established areas of the energy value chain, such as upstream oil and gas, industry faces the challenge of an ageing workforce. In nascent areas of the value chain, such as renewable energy generation, the industry faces a shortage of professionals with the requisite knowledge and experience. This lack of talent is further compounded by the absence of professional institutions to provide education, accreditation, standards and support structures to sector employees. Industry should look to not only build internal training programmes to better educate workforces, but should also focus on attracting and retaining new talent by working with universities and governments to promote the field of engineering for those entering higher education.

Civil Society – Building greater transparency into the system: Making changes to energy architecture requires building support from all stakeholders in civil society, including the public at large. The establishment of communication channels is therefore a necessary step towards promoting better understanding of the risks and benefits associated with energy architecture change. For example, the siting of new forms of energy architecture, such as large onshore wind farms, can lead to public concerns and opposition, commonly referred to as NIMBYism (Not In My BackYard). Civil society groups play an important role in communicating such change to local communities.

Beyond the provision of information, civil society should be engaged in the policy-making process for deciding the future of New Energy Architecture in the context of overall national strategies to meet the three imperatives of the energy triangle. Enhancing public involvement in shaping the future of the sector is essential to build trust and ensure broad support.

The creation of a New Energy Architecture also requires behavioural change on the part of consumers. Indeed, consumers must play an increasingly large role in the energy sector if we are to transition to an energy lean world. This requires consumers to gain a greater appreciation of the costs and complexity of the energy sector, to enable them to make better choices that optimize their energy use. In some instances this will require lifestyle changes such as using public forms of transport over private, reducing air conditioning levels and changing consumption patterns to reduce peak demand in the electricity sector. In other cases, changes in culture will need to be driven by the consumer. This will see changes in the acceptability of energy wastage and inefficiency. These changes can be further enabled by a range of technologies, including smart meters, and businesses, such as energy service providers.

Multiparty Action: Building Partnerships

Multistakeholder coalitions – Tackle problems together

A successful transition will not be created by stakeholder groups operating in silos. Coalitions will be required to meet the New Energy Architecture challenge, each leveraging their own expertise within a common policy framework. Key areas of focus, highlighted during the course of discussions at World Economic Forum regional events, include financing energy architecture change and creating an appropriate social compact to enable change.

The creation of a New Energy Architecture requires a large amount of capital investment. The IEA estimates that a global investment of US$ 38 trillion is required in energy supply infrastructure over the period 2011 to 2035.[79] In most countries, New Energy Architecture will not be built without the active contribution of private capital. Yet the risks of such investment are high and the potential returns hard to estimate. To invest with confidence, industry will need stable, policy regimes to allay both the regulatory risk of the initial investment and refinancing risk. During the long lead times involved, there will likely be national elections, as well as several changes of governments during their operating life. There is therefore a need for policy support not only from the incumbent government, but also a long-term strategy with broad-based political support.

Developing such a strategy will involve conducting public consultations to achieve a national consensus on a way forward that goes beyond an individual political party. Governments will also have to work with the energy industry and financial institutions to mitigate risk and guarantee investments, particularly in segments of the energy sector that are deemed to be risky by institutional investors, as is the case for many renewable energy projects. Public-private partnerships are a tool that can be used to effectively allocate risk across the various stakeholders. On a global scale, the Global Green Growth Forum, supported by South Korea, Mexico and Denmark, has provided an international framework for the promotion of such public-private relationships.[80]

Progressing with energy architecture change requires not only financial support, but also the establishment of a social compact between industry, government and civil society. There is a clear need for the sector to build and maintain public trust in communities that surround the fence lines of the large-scale infrastructure that dominates the energy sector. A number of recent incidents have brought this to light – ranging from the Deepwater Horizon oil spill to the Fukushima disaster – as well as the growing controversy over the use of hydraulic fracturing in shale gas production. Industry has already begun to take steps to re-instil public confidence – as seen in the release of Shell's Onshore Tight/Shale Oil & Gas Operating Principles – but more needs to be done.[81]

Examples of the importance of multistakeholder approaches to create enabling environments were brought out during the course of the country studies on Japan and India. In the case of Japan, we focus on an area where stronger coalitions are required. For India, we look at where the institution of a multistakeholder environment has achieved some successes.

Japan – Rethink Approach to Nuclear Energy

Nuclear energy will continue to play an important role in Japan's diversified energy mix. Yet, three-fifths of the public say they have little confidence in nuclear power.[82] Rebuilding public confidence in the nuclear sector will require fundamental changes in how it is run and regulated, requiring a multistakeholder effort. The first step in achieving this will be through transparent communication with the public. This may be further bolstered through the establishment of a fully independent regulatory agency to appraise new and existing facilities for quality and safety compliance.

It is also important that Japan clearly communicates the lessons learned from the disaster to the international community. In many parts of the world the appetite for nuclear generation remains unchanged. China is still predicted to grow from less than 3% of global nuclear capacity to 27% in 2050.[83] India is also pushing on with expanding its capacity and is expected to contribute up to 11% of global production in the same time period. The Global Nuclear Energy Partnership (GNEP) provides a framework for countries seeking to expand the use of nuclear energy while promoting non-proliferation and secure supplies of fuel. The IAEA also promotes a global safety regime, including the Convention on Nuclear safety. Japan must seek to use these international bodies to share the knowledge gained post-Fukushima so that its experiences can be used to prevent similar incidents elsewhere.

79 World Energy Outlook 2011. Paris: International Energy Agency
80 The Global Green Growth Forum, http://www.globalgreengrowthforum.com/the-forum.
81 Shell Onshore Tight/Shale Oil & Gas Operating Principles, http://www.shell.us/home/content/usa/aboutshell/shell_businesses/onshore/principles.
82 "Energy in Japan: Bright ideas needed". The Economist. 17 September 2011.
83 Technology Road Map: Nuclear Energy. 2010. Paris: International Energy Agency.

Finally, the Fukushima incident has revealed a number of weaknesses within Japan's capabilities in the nuclear value chain, particularly in relation to managing cooling shut-down, unbundling spent fuel storage and contaminated water disposal, and decommissioning. Japan should look to invest in R&D to overcome these challenges, bringing in international expertise to assist based on a combined government and industry effort.

The implementation of a multistakeholder approach will help Japan tackle the challenges within its nuclear sector.

India – Providing access to modern forms of energy for all

Energy poverty continues to blight a significant portion of the population, with fossil fuels currently costing a disproportionate portion of what is for many very modest incomes. Providing energy access for all is therefore a key objective if India is to deliver on its target of 9-9.5% GDP growth in 2012-2017 while achieving the Millennium Development Goals; a set of development targets to be reached by 2015 include reducing the population under the poverty line to below 20%.[84]

Since the launch of the "Power for all by 2012" initiatives in 2001, India has created a solid policy platform to expand energy access. In February 2005 a large-scale electrification effort, the Rajiv Gandhi Grameen Vidutikaran Yojana (RGGVY) scheme, was launched by the Ministry of Power to speed up rural electrification. Since 2005 the Rural Village Electrification (RVE) programme of the Ministry of New and Renewable Energies has been supplementing the efforts of the RGGVY through complementary measures for the provision of basic lighting/ electricity facilities through renewable energy sources.[85] While further work needs to be done to expand rural electrification, as highlighted in New Energy Architecture: India, much has been achieved – as of 30 June 2011, work in 97,940 villages had been completed for RGGVY, with 166 million free connections to below-poverty-line households.[86]

The successes of the electrification programme have been a consequence of public-private financing mechanisms and the involvement of civil society groups to boost adoption among rural communities. Under the RGGVY, the Ministry of Power grants 90% of the cost of rural electrification projects. States cover the remaining 10% of the cost either from their own funds or through loans from the Rural Electrification Corporation (REC), the Power Finance Corporation (PFC) and the Indian Renewable Energy Development Agency (IREDA). Electricity connections are free for customers below the poverty line. To facilitate recovery of customer payments from those above the poverty line, the RGGVY has ordered the creation and deployment of franchisees. Acknowledging that most of the burden of doing without electricity falls on women, the Ministry of Power has arranged for women to be represented in district committees, thereby helping in the coordination and control of electrification extensions within their district.

A continued multistakeholder approach will help further the cause of rural electrification in India.

Cross-regional partnerships – Take global accountability

Energy architecture is as much a global issue, as it is a local one. Enabling an effective transition therefore requires stakeholders to work together across national boundaries. As has been seen with regard to climate change, the weak global deal created at the 2009 UN Climate Change Conference in Copenhagen has created much uncertainty, resulted in politically-driven policies and created a patchwork of different regulations.

As policy-makers seek to overcome this impasse, the world should look towards alternative means of collaboration, such as mobilizing technical resources from the developed world to tackle the challenges of the developing world. For example, the Renewable Energy and Energy Efficiency Partnership, an NGO launched by the government of the United Kingdom with a number of international partners, has thus far funded over 150 projects,[87] mainly focusing on emerging targets such as India, China and Brazil with significant success.

There are also significant opportunities for creating regional partnerships to promote energy security. During a workshop on New Energy Architecture in Tokyo, participants called for the creation of regional energy architecture. Such a move would promote energy security since the larger a regional grid, the greater the options for managing system load by relying on this larger suite of resources. Within an adequately regulated framework and with independent system operations, the right incentives would be in place to ensure efficient sharing of resources across jurisdictions.

A concluding caveat on the pace of implementation

It is important to recognize that the creation of enabling environments will not be "big bang" moments. Energy architecture is large and complex, and enormous legacy systems remain in place. The complexity and scale involved will require an incremental approach on the part of stakeholders, particularly if they are to manage the economic impacts of the write-down of legacy assets.

While we are witnessing a period of extensive change, the transition will be drawn out. It may not be until after 2030 that we see a firmly embedded New Energy Architecture, as the cumulative effect of innovation across the four pillars of the enabling environment takes hold and makes its full impact felt.

84 Millennium Development Goals Country Report: India. 2005. UNICEF.
85 This applies to populations of less than 100 inhabitants; the electrification of villages comprising more than 100 inhabitants will usually be taken on by the RGGVY scheme through its decentralized, distribution and generation (DDG) projects. To avoid overlap of efforts close coordination between the RGGVY and the MNRE is ensured mainly through the Rural Electrification Corporation.
86 Bharat Nirman – Electrification: A Business Plan, http://www.powermin.nic.in/bharatnirman/bharatnirman.asp.
87 http://www.reeep.org.

Appendices:
The Creation of the Energy Architecture Performance Index

Appendix A: Computation and Structure of the Energy Architecture Performance Index

This appendix presents the structure of the Energy Architecture Performance Index (EAPI). The index is designed to understand how countries are performing in relation to each of the imperatives of the energy triangle: economic growth and development; environmental sustainability; and energy access and security. A sub-index was created for each of these imperatives. For each sub-index a set of key performance indicators (KPIs) were chosen based on an understanding of the objectives of the imperative:

- **Economic growth and development:** This sub-index aims to measure the extent to which energy architecture supports, rather than detracts from, economic growth and development. The following KPIs were chosen:
  - Energy intensity
  - Cost of energy imports as a share of GDP
  - Share of mineral products in export
  - GDP per capita
  - HDI
- Environmental sustainability: This sub-index aims to measure the extent to which energy architecture has been constructed in a manner that reduces negative environmental externalities. The following KPIs were chosen:
  - Carbon intensity of energy use
  - Share of non-carbon energy sources
  - Outdoor air pollution
  - Water scarcity
- Energy access and security: This sub-index aims to measure the extent to which energy architecture is at risk to an energy security impact, and whether adequate access to energy is provided to all parts of the population. The following KPIs were chosen:
  - Import dependence
  - Diversity of supply
  - Quality of electricity supply
  - Access to modern forms of energy

To create comparative data that could be aggregated into an overarching index, the data has been normalized. An individual index was created for each KPI. Performance for each KPI is expressed as a value between 0 and 1, calculated as per the below expression:

$$\text{Score} = \begin{cases} 0, & x > \text{BASE} \\ \dfrac{x - \text{BASE}}{\text{TOP} - \text{BASE}}, & \text{TOP} > x > \text{BASE} \\ 1, & x < \text{TOP} \end{cases}$$

Instead of using the maximum and minimum values of each data set, anomalies were first removed by establishing TOP and BASE levels. TOP is the point of the raw data that is mapped to 1 and is calculated based from the mean +/- two standard deviations (dependent on whether a high or low value for the original metric is "good" or "bad"). BASE is the point of the raw data that is mapped to 0 and is calculated from the mean +/- two standard deviations (dependent on whether a high or low value for the original metrics is "good" or "bad"). All other values then follow a linear distribution from the BASE to the TOP.

In the case of diversity of supply, the raw data was first converted into a Simpson's Diversity Index to measure the distribution of energy supply across seven supply sources: coal and peat; crude oil and oil products; gas; nuclear; hydro; other renewables such as geothermal and solar; and combustible renewable and waste. The Simpson's Diversity Index is expressed using the below function, where n is the relative abundance of each energy source:

$$D = 1 - \left(\frac{\sum n(n-1)}{N(N-1)} \right)$$

To create the sub-indices for environmental sustainability, as well as energy access and security, the individual indices for each KPI were aggregated by expressing each as a share of 1, with all KPIs evenly weighted (i.e. each indicator could contribute up to 0.25 to the sub-index). In the case of economic growth and development, energy intensity was given a higher weighting. This was in response to feedback received from the project steering board, which emphasized the importance of demand side management measures. Energy intensity therefore accounts for 30% of the index, with the remaining four indicators accounting for 70% of the index. The scores for GDP per capita and HDI were combined to provide a base level indication for economic growth and development, and together account for 17.5% of the index.

To create the overall score for each country the scores on each sub-index were added together, with the maximum score on the EAPI therefore being 3.

Historic data

To understand how countries have progressed over time, historic data was collected for the years 1999 to 2008, and also for 1990. To complete the normalization process for historic data the TOP and BASE values used were those from today's index. The historic indicators thus show how countries are performing in comparison to today.

In a number of instances historic data was not available. In these instances, data was kept constant from the last available year in which it was available. This applies to the following indicators:

- Economic growth and development
  - Share of mineral products in export: Data was only available for 2005-2008. In calculations of the index for the years 1999-2004 and 1980, the data from 2005 was kept constant.

- Environmental sustainability
  - Water scarcity: Data was only available for 2000. This was kept constant across the time periods covered.

- Energy access and security
  - Quality of electricity supply: Data was only available for 2005-2008. In calculations of the index for the years 1999-2004 and 1980, the data from 2005 was kept constant.
  - Access to modern forms of energy: Data was only available for 2003. This was kept constant across the time periods covered.

Creating archetypes

Archetypes were created by grouping those nations that displayed common features during the KPI analysis, and are defined as follows:

- Rationalize: Those nations that scored in the top quartile for economic growth and development

- Capitalize: Those nations that scored outside the top quartile for economic growth and development, and in the top quartile for energy access and security

- Grow: Those nations that scored below the top quartile for economic growth and development, and energy access and security, but above the bottom quartile for energy access and security

- Access: Those nations that scored in the bottom quartile for energy access and security

A review of countries that fell towards the boundaries of the above criteria was completed. This was in recognition of the fact that many countries display features of more than one archetype. In these instances, countries have been allocated to the archetype that represents their most pressing need.

Appendix B: Technical Notes and Sources for the Energy Architecture Performance Index

This appendix presents the technical descriptions and sources for the 13 KPIs of the Energy Architecture Performance Index. The most complete data set available for the indicators was from 2008. Data from this year was therefore used, unless otherwise unavailable.

Economic Growth and Development

Energy intensity

GDP per unit of energy use (PPP $ per kg of oil equivalent) 2008

Provides an indication of the efficiency of energy use, and whether there is an opportunity to improve energy availability by reducing energy intensity. Total primary energy supply is calculated as indigenous production plus imports, removing exports, international marine bunkers, international aviation bunkers, and then adding or taking away stock changes. (Source: The World Bank)

Cost of energy imports as a share of GDP

Value of import of fuels/GDP 2008

Provides an indication of the extent to which the energy sector has a negative impact on growth. Import bill is calculated based on the import of fuels (mineral fuels, lubricants and related materials) as classified under the Standard International Trade Classification, Revision 3, Eurostat. (Source: WTO Statistical Database)

Share of mineral products in export

Mineral products in export/national exports 2008

Provides an indication of the efficiency of energy use, and whether there is an opportunity to improve energy availability by reducing energy intensity. The share of mineral products includes minerals fuels as classified under the Harmonized System Codes of Chapter 27, which covers mineral fuels, mineral oils and products of their distillation; bituminous substances and mineral waxes. (Source: ITC)

GDP per capita

GDP (PPP) (current $) per capita 2008

GDP per capita is gross domestic product divided by mid-year population. GDP is the sum of gross value added by all resident producers in the economy plus any product taxes and minus any subsidies not included in the value of the products, using purchasing power parity rates. (Source: The World Bank)

HDI

Human Development Index 2008

The Human Development Index is used to assess comparative levels of development in countries and includes PPP adjusted income, literacy and life expectancy as its three main matrices. The HDI is only one of many possible measures of the well-being of a society, but it can serve as a proxy indicator of development. HDI has been shown to correlate well with per capita energy use. A certain minimum amount of energy is required to guarantee an acceptable standard of living (e.g. 42 GJ per capita), after which raising energy consumption yields only marginal improvements in the quality of life. (Source: The World Bank)

Environmental Sustainability

Carbon intensity of energy use

Carbon intensity (total carbon dioxide emissions from the consumption of energy per dollar of GDP using market exchange rates (metric tons of carbon dioxide per thousand year 2005 US dollars)|2008
Estimates carbon dioxide emissions from the consumption and flaring of fossil fuels, per thousand dollars of GDP, using market exchange rates. When there are several fuels, as in this case, carbon intensity is based on their combined emissions coefficients weighted by their energy consumption levels. (Source: EIA)

Share of non-carbon energy sources

Alternative and nuclear energy/TPES 2008

Clean energy is non-carbon energy that does not produce carbon dioxide when generated. It includes hydropower, nuclear, geothermal and solar power among others. This is taken as a share of total primary energy use. (Source: The World Bank)

Outdoor air pollution

PM10 [mg/m3] per annum 2008

Particulate matter concentrations refer to fine suspended particulates less than 10 microns in diameter (PM10) that are capable of penetrating deep into the respiratory tract and causing significant health damage. Data for countries and aggregates for regions and income groups are urban-population weighted PM10 levels in residential areas of cities with more than 100,000 residents. The estimates represent the average annual exposure level of the average urban resident to outdoor particulate matter. (Source: The World Bank)

Water scarcity

Freshwater withdrawals as a share of internal resources 2000

Annual freshwater withdrawals refer to total water withdrawals, not counting evaporation losses from storage basins, and are a proxy measure for water scarcity. Withdrawals also include water from desalination plants in countries where they are a significant source. Withdrawals can exceed 100% of total renewable resources where extraction from non-renewable aquifers or desalination plants is considerable or where there is significant water reuse. Withdrawals for agriculture and industry include withdrawals for irrigation and livestock production and for direct industrial use (including withdrawals for cooling thermoelectric plants). Withdrawals for domestic uses include drinking water, municipal use or supply, and use for public services, commercial establishments, and homes. Data are for the most recent year available for 1987-2002. (Source: AQUASTAT)

Energy Access and Security

Import dependence

Net imports/TPES 2008

Provides an indication of the extent to which a nation is dependent on sourcing imports to meet energy demand. Net imports are calculated across all energy sources, as well as carriers including electricity and heat. This is taken as a share of total primary energy supply. Dependence on energy imports exposes affected economies to potential price risk fluctuations. (Source: World Bank)

Diversity of supply

Simpson's Diversity Index 2008

Greater diversity in sources of supply will reduce dependence on any one fuel, and therefore increase energy security. Given the interdependence of economic growth and energy consumption, access to a stable energy supply is a major political concern and a technical and economic challenge. All else being equal, the more reliant an energy system is on a single energy source, the more susceptible the energy system is to serious disruptions. Examples include disruptions to oil supply, unexpectedly large and widespread periods of low wind or solar insulation (e.g. due to weather), or the emergence of unintended consequences of any supply source. (Source: IEA; Author's calculations)

Quality of electricity supply

Rating from 0 to 7 2008

Assesses the quality of the electricity supply within a country based on lack of interruptions and lack of voltage fluctuations. This has been used in favour of measures of the percentage of the population supplied with electricity, as we believe that it is a nuanced measure more suited to the purposes of a global comparison. This is taken from the World Economic Forum's Executive Opinion Survey, in which respondents were asked: How would you assess the quality of the electricity supply (lack of interruptions and lack of voltage fluctuations) of your country? [1 = insufficient and suffers frequent interruptions; 7 = sufficient and reliable]. (Source: World Economic Forum, Global Competitiveness Index)

Access to modern forms of energy
Percentage of the population using solid fuels|2008
Provides an indication of whether the population has access to modern sources of energy. Solid fuels include biomass, such as wood, charcoal, crops or other agricultural waste, as well as dung, shrubs and straw, and coal.
Although solid fuels are used for heating purposes, the World Health Statistics database is a compilation of information on the main fuel used for cooking purposes only. (Source: World Health Organization)

Appendix C: Comparison of Energy Architecture Performance Index Performance by Archetypes

The below set of tables provide an overview of the performance of a select group of countries on the Energy Architecture Performance Index (EAPI) from each of the archetypes.

The first three tables provide an overview of performance in relation to each element of the energy triangle, with data listed for scores on each KPI, as well as the accompanying raw data.

The final table is a heat map indicating the difference between a country, and other selected archetype comparators. The heat map provides a sense of the distance in scores that separates the selected country from other members of the archetype. Blue-shaded cells and grey-shaded cells indicate that country scores or ranks respectively higher or lower than the comparator, while no shading means that there is no significant divergence. The darker the nuance, the greater the difference in performance

1. Rationalize

Economic Growth and Development	GDP per capita		HDI index		Import bill as a share of GDP		Energy intensity		Share of mineral products in export	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Canada	0.90	32790	0.91	0.89	0.84	0.03	0.54	0.21	0.64	31.74
Denmark	0.88	32312	0.87	0.86	0.86	0.03	0.92	0.09	0.88	10.72
France	0.77	28176	0.87	0.87	0.77	0.05	0.81	0.13	0.93	6.33
Germany	0.82	29895	0.90	0.88	0.75	0.05	0.85	0.11	0.96	3.54
Italy	0.75	27416	0.84	0.85	0.70	0.06	0.92	0.09	0.95	5.12
Japan	0.79	29027	0.90	0.88	0.87	0.03	0.84	0.12	0.97	3.21
New Zealand	0.67	24573	0.94	0.90	0.72	0.06	0.77	0.14	0.91	8.02
Sweden	0.89	32513	0.91	0.89	0.78	0.05	0.76	0.14	0.89	9.52
Switzerland	0.95	34838	0.88	0.87	0.82	0.04	0.95	0.08	0.95	5.08
United Kingdom	0.87	31773	0.83	0.85	0.87	0.03	0.91	0.10	0.81	16.99
United States	1.00	40309	0.93	0.90	0.90	0.02	0.69	0.16	0.89	9.56

Environmental Sustainability	Carbon intensity		Share of non-carbon energy		Outdoor air pollution		Freshwater withdrawals	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Canada	0.77	0.50	1.00	21.63	0.91	15.00	0.96	1.61
Denmark	0.95	0.20	0.17	3.32	0.89	16.26	0.59	17.40
France	0.95	0.19	1.00	45.29	0.93	12.94	0.63	15.88
Germany	0.90	0.28	0.67	13.30	0.89	16.21		
Italy	0.92	0.25	0.26	5.13	0.81	23.33	0.41	24.83
Japan	0.91	0.26	0.79	15.56	0.76	27.14	0.51	20.56
New Zealand	0.87	0.34	1.00	27.03	0.95	11.93	0.99	0.65
Sweden	0.98	0.14	1.00	45.92	0.96	10.52	0.96	1.64
Switzerland	1.00	0.11	1.00	39.60	0.82	22.36	0.85	6.47
United Kingdom	0.93	0.23	0.36	7.09	0.94	12.67		
United States	0.81	0.44	0.57	11.20	0.86	19.40	0.60	16.78

Energy Access and Security	Import dependence		Quality of electricity supply		Solid fuel use		Diversity of supply	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Canada	0.64	-52.71	0.93	6.56	1.00	5.00	0.93	0.76
Denmark	0.59	-39.88	1.00	6.89	1.00	5.00	0.90	0.74
France	0.22	48.73	0.98	6.79	1.00	5.00	0.84	0.70
Germany	0.17	60.00	0.97	6.75	1.00	5.00	0.94	0.76
Italy	0.06	84.70	0.69	5.34	1.00	5.00	0.76	0.65
Japan	0.08	82.12	0.97	6.75	1.00	5.00	0.86	0.71
New Zealand	0.37	12.11	0.66	5.19	1.00	5.00	0.96	0.77
Sweden	0.28	32.97	0.97	6.74	1.00	5.00	0.93	0.75
Switzerland	0.20	52.32	0.98	6.80	1.00	5.00	0.88	0.72
United Kingdom	0.34	20.03	0.89	6.37	1.00	5.00	0.83	0.69
United States	0.31	25.29	0.91	6.47	1.00	5.00	0.90	0.74

Country	Economic growth & development	GDP per capita	HDI	Import bill as a share of GDP	Energy intensity	Share of mineral products in export	Environmental sustainability	Carbon intensity	Share of non-carbon energy	Outdoor air pollution	Freshwater withdrawals	Energy access & security	Import dependence	Quality of electricity supply	Solid fuel use	Diversity of supply
Japan	**0.87**	**0.79**	**0.90**	**0.87**	**0.84**	**0.97**	**0.74**	**0.91**	**0.79**	**0.76**	**0.51**	**0.73**	**0.08**	**0.97**	**1.00**	**0.86**
Canada	0.13	-0.10	-0.01	0.03	0.31	0.33	-0.17	0.14	-0.21	-0.15	0.4	-0.15	-0.57	0.04	0.00	-0.07
Denmark	-0.02	-0.09	0.03	0.00	-0.07	0.09	0.10	-0.03	0.62	-0.13	-0.07	-0.15	-0.51	-0.03	0.00	-0.04
France	0.04	0.02	0.03	0.09	0.03	0.04	-0.13	-0.04	-0.21	-0.17	-0.11	-0.03	-0.14	-0.01	0.00	0.02
Germany	0.01	-0.02	-0.01	0.11	0.00	0.00	-0.08	0.01	0.11	-0.13		-0.04	-0.09	0.00	0.00	-0.08
Italy	0.03	0.04	0.06	0.17	-0.07	0.02	0.14	-0.01	0.53	-0.05	0.10	0.10	0.01	0.28	0.00	0.10
New Zealand	0.07	0.12	-0.04	0.14	0.08	0.06	-0.21	0.05	-0.21	-0.18	-0.47	-0.02	-0.29	0.31	0.00	-0.10
Sweden	0.03	-0.10	-0.01	0.08	0.08	0.07	-0.23	-0.07	-0.21	-0.20	-0.45	-0.07	-0.21	0.00	0.00	-0.07
Switzerland	-0.05	-0.16	0.02	0.04	-0.11	0.02	-0.17	-0.09	-0.21	-0.06	-0.33	-0.04	-0.13	-0.01	0.00	-0.02
United Kingdom	0.01	-0.08	0.06	-0.01	-0.06	0.16	0.00	-0.01	0.43	-0.17		-0.04	-0.26	0.08	0.00	0.03
United States	0.01	-0.21	-0.03	-0.03	0.15	0.07	0.04	0.11	0.22	-0.09	-0.09	-0.05	-0.24	0.06	0.00	-0.04

Score Difference -0.7 -0.4 -0.1 0.1 0.4 0.7

This heat map allows for a reading of Japan's performance in the EAPI in relative terms. It provides a sense of the distance in scores that separates Japan from other members of the Rationalize archetype. Blue-shaded cells and grey-shaded cells indicate that Japan scores or ranks respectively higher or lower than the comparator, while no shading means that there is no significant divergence. The darker the shading, the greater the difference in performance.

2. Capitalize

Economic Growth and Development	GDP per capita		HDI index		Import bill as a share of GDP		Energy intensity		Share of mineral products in export	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Azerbaijan	0.09	3477.7	0.57	0.70	1.00	0.00	0.58	0.20	0.00	97.21
Brunei Darussalam	1.00	46681	0.75	0.80			0.62	0.19	0.00	97.98
Colombia	0.18	6853.9	0.53	0.68	0.97	0.01	0.96	0.08	0.45	47.95
Iraq	0.07	2895.7			0.89	0.02	0.06	0.36	0.00	98.99
Kazakhstan	0.21	7742.5	0.58	0.71	0.63	0.08	0.00	0.42	0.14	74.60
Kuwait	1.00	39291	0.69	0.77			0.56	0.20	0.00	94.72
Oman	0.50	18516			0.85	0.03	0.35	0.27	0.10	78.13
Qatar	1.00	64396	0.74	0.80	1.00	0.00	0.37	0.26	0.00	92.54
Russian Federation	0.28	10246	0.59	0.72	0.98	0.01	0.29	0.29	0.22	67.48
Saudi Arabia	0.54	19964	0.65	0.75	0.97	0.01	0.27	0.29	0.00	89.62
United Arab Emirates	1.00	4559	0.77	0.81	0.94	0.02	0.45	0.24	0.39	53.07

Environmental Sustainability	Carbon intensity		Share of non-carbon energy		Outdoor air pollution		Freshwater withdrawals	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Azerbaijan	0.16	1.56	0.07	1.44	0.70	32.59		
Brunei Darussalam	0.45	1.06	0.00	0.00	0.48	50.62		
Colombia	0.84	0.38	0.66	12.99	0.85	19.94	0.99	0.60
Iraq	0.28	1.35	0.01	0.14	0.00	138.14	0.00	187.47
Kazakhstan	0.00	2.36	0.05	0.91	0.90	15.38	0.01	42.06
Kuwait	0.58	0.84	0.00	0.00	0.00	95.13		
Oman	0.41	1.13	0.00	0.00	0.00	93.76	0.00	94.71
Qatar	0.63	0.75	0.00	0.00	0.67	35.28	0.00	348.04
Russian Federation	0.03	1.78	0.42	8.36	0.90	15.90		
Saudi Arabia	0.35	1.23	0.00	0.00	0.00	103.88		
United Arab Emirates	0.43	1.10	0.00	0.00	0.02	88.83	0.00	1679.33

Energy Access and Security	Import dependence		Quality of electricity supply		Solid fuel use		Diversity of supply	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Azerbaijan	1.00	-338.32	0.40	3.91	0.97	7.00	0.42	0.45
Brunei Darussalam	1.00	-482.14	0.70	5.44	1.00	5.00	0.25	0.34
Colombia	1.00	-204.18	0.63	5.07	0.89	13.09	0.89	0.73
Iraq	1.00	-246.29			0.99	5.44	0.00	0.09
Kazakhstan	0.88	-108.95	0.47	4.28	0.90	12.00	0.74	0.64
Kuwait	1.00	-481.20	0.55	4.65	1.00	5.00	0.46	0.47
Oman	1.00	-286.12	0.76	5.71	1.00	5.00	0.39	0.43
Qatar	1.00	-417.58	0.82	6.02	1.00	5.00	0.30	0.37
Russian Federation	0.77	-82.59	0.58	4.81	0.97	7.00	0.74	0.64
Saudi Arabia	1.00	-258.31	0.77	5.76	1.00	5.00	0.46	0.47
United Arab Emirates	1.00	-208.95	0.90	6.41	1.00	5.00	0.17	0.29

Country	**Economic growth & development**	GDP per capita	HDI	Import bill as a share of GDP	Energy intensity	Share of mineral products in export	**Environmental sustainability**	Carbon intensity	Share of non-carbon energy	Outdoor air pollution	Freshwater withdrawals	**Energy access & security**	Import dependence	Quality of electricity supply	Solid fuel use	Diversity of supply
Kazakhstan	**0.27**	**0.21**	**0.58**	**0.63**	**0.00**	**0.14**	**0.24**	**0.00**	**0.05**	**0.90**	**0.01**	**0.75**	**0.88**	**0.47**	**0.90**	**0.74**
Azerbaijan	-0.19	0.12	0.01	-0.37	-0.58	0.14	-0.07	-0.16	-0.03	0.21		0.05	-0.12	0.08	-0.07	0.31
Brunei Darussalam	-0.32	-0.79	-0.18		-0.62	0.14	-0.07	-0.45		0.42		0.01	-0.12	-0.23	-0.10	0.48
Colombia	-0.39	0.02	0.05	-0.35	-0.96	-0.31	-0.60	-0.84	-0.61	0.05	-0.98	-0.10	-0.12	-0.16	0.02	-0.15
Iraq	0.03	0.13		-0.26	-0.06	0.14	0.17	-0.28	0.04	0.90	0.01	0.08	-0.12		-0.09	0.74
Kuwait	-0.29	-0.79	-0.11		-0.56	0.14	0.05	-0.58		0.90		0.00	-0.12	-0.07	-0.10	0.28
Oman	-0.17	-0.30		-0.22	-0.35	0.04	0.14	-0.41	0.05	0.90		-0.04	-0.12	-0.29	-0.10	0.35
Qatar	-0.32	-0.79	-0.16	-0.37	-0.37	0.14	-0.09	-0.63	0.05	0.24		-0.03	-0.12	-0.35	-0.10	0.43
Russian Federation	-0.18	-0.07	-0.01	-0.35	-0.29	-0.08	-0.21	-0.03	-0.38	0.01		-0.02	0.11	-0.11	-0.07	-0.01
Saudi Arabia	-0.19	-0.34	-0.07	-0.35	-0.27	0.14	0.12	-0.35	0.05	0.90		-0.06	-0.12	-0.30	-0.10	0.27
United Arab Emirates	-0.41	-0.79	-0.19	-0.31	-0.45	-0.25	0.13	-0.43	0.05	0.88	0.01	-0.02	-0.12	-0.43	-0.10	0.57

Score Difference -0.7 -0.4 -0.1 0.1 0.4 0.7

This heat map allows for a reading of Kazakhstan's performance in the EAPI in relative terms. It provides a sense of the distance in scores that separates Kazakhstan from other members of the Capitalize archetype. Blue-shaded cells and grey-shaded cells indicate that Kazakhstan scores or ranks respectively higher or lower than the comparator, while no shading means that there is no significant divergence. The darker the shading, the greater the difference in performance.e.

3. Grow

Economic Growth and Development	GDP per capita		HDI index		Import bill as a share of GDP		Energy intensity		Share of mineral products in export	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Chile	0.30	11277	0.71	0.78	0.57	0.09	0.78	0.14	0.74	23.24
Hungary	0.44	16217	0.76	0.80	0.29	0.14	0.77	0.14	0.96	3.81
India	0.05	2036.9	0.20	0.51	0.49	0.10	0.59	0.19	0.65	30.92
Indonesia	0.08	2983	0.36	0.59	0.62	0.08	0.46	0.24	0.62	33.46
Korea, Rep.	0.59	21630			0.39	0.12	0.64	0.18	0.90	9.45
Mexico	0.31	11646	0.65	0.75	0.90	0.02	0.84	0.12	0.79	18.46
China	0.09	3598.6	0.47	0.65	0.78	0.05	0.29	0.29	0.97	2.66
South Africa	0.21	7992.8	0.36	0.59	0.64	0.07	0.32	0.28	0.72	24.83
Thailand	0.17	6309.3	0.46	0.65	0.30	0.14	0.56	0.21	0.91	7.91
Turkey	0.26	9802	0.52	0.67	0.63	0.08	0.89	0.10	0.92	7.44
Vietnam	0.05	1937.2			0.38	0.13	0.36	0.27	0.77	20.72

Environmental Sustainability	Carbon intensity		Share of non-carbon energy		Outdoor air pollution		Freshwater withdrawals	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Chile	0.78	0.49	0.34	6.63	0.35	61.55	0.97	1.28
Hungary	0.79	0.48	0.77	15.16	0.90	15.60		
India	0.26	1.38	0.12	2.42	0.38	59.23	0.00	47.84
Indonesia	0.37	1.19	0.39	7.68	0.22	72.35	0.87	5.61
Korea, Rep.	0.75	0.55	0.89	17.49	0.72	30.76		
Mexico	0.78	0.48	0.34	6.73	0.70	32.69		
China	0.00	2.14	0.18	3.53	0.30	65.61		
South Africa	0.08	1.70	0.13	2.64	0.82	22.13	0.34	27.86
Thailand	0.32	1.28	0.03	0.57	0.42	55.31		
Turkey	0.77	0.50	0.23	4.57	0.64	37.06	0.56	18.50
Vietnam	0.16	1.57	0.19	3.76	0.46	52.71		

Energy Access and Security	Import dependence		Quality of electricity supply		Solid fuel use		Diversity of supply	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Chile	0.12	71.34	0.68	5.33	1.00	5.00	0.70	0.61
Hungary	0.17	60.33	0.68	5.29	1.00	5.00	0.88	0.73
India	0.32	24.58	0.24	3.15	0.23	59.69	0.83	0.69
Indonesia	0.73	-74.65	0.39	3.86	0.25	58.36	0.95	0.77
Korea, Rep.	0.08	80.29	0.85	6.15	1.00	5.00	0.87	0.72
Mexico	0.54	-29.34	0.42	4.03	0.86	15.00	0.66	0.59
China	0.40	5.82	0.56	4.72	0.40	48.00	0.54	0.52
South Africa	0.51	-21.16	0.29	3.36	0.83	17.27	0.46	0.47
Thailand	0.25	40.41	0.71	5.48	0.72	25.00	0.87	0.72
Turkey	0.12	70.58	0.45	4.15			0.88	0.72
Vietnam	0.50	-20.14	0.26	3.22	0.22	61.00	0.86	0.71

Country	**Economic growth & development**	GDP per capita	HDI	Import bill as a share of GDP	Energy intensity	Share of mineral products in export	**Environmental sustainability**	Carbon intensity	Share of non-carbon energy	Outdoor air pollution	Freshwater withdrawals	**Energy access & security**	Import dependence	Quality of electricity supply	Solid fuel use	Diversity of supply
India	**0.42**	**0.05**	**0.20**	**0.49**	**0.59**	**0.65**	**0.19**	**0.26**	**0.12**	**0.38**	**0.00**	**0.41**	**0.32**	**0.24**	**0.23**	**0.83**
Chile	-0.22	-0.25	-0.50	-0.08	-0.18	-0.09	-0.42	-0.52	-0.21	0.03	-0.97	-0.22	0.20	-0.44	-0.77	0.13
Hungary	-0.24	-0.39	-0.55	0.21	-0.18	-0.31	-0.63	-0.52	-0.64	-0.52		-0.28	0.15	-0.43	-0.77	-0.05
Indonesia	-0.01	-0.03	-0.15	-0.13	0.14	0.03	-0.27	-0.11	-0.27	0.16	-0.87	-0.17	-0.42	-0.14	-0.02	-0.12
Korea, Rep.	-0.21	-0.54		0.10	-0.05	-0.25	-0.59	-0.48	-0.76	-0.34		-0.29	0.23	-0.61	-0.77	-0.04
Mexico	-0.29	-0.26	-0.44	-0.41	-0.25	-0.14	-0.42	-0.52	-0.22	-0.32		-0.22	-0.23	-0.18	-0.63	0.17
China	-0.07	-0.04	-0.26	-0.29	0.31	-0.33	0.03	0.26	-0.06	0.08		-0.07	-0.08	-0.32	-0.16	0.29
South Africa	-0.01	-0.16	-0.16	-0.15	0.28	-0.07	-0.15	0.18	-0.01	-0.44	-0.34	-0.11	-0.19	-0.04	-0.59	0.38
Thailand	-0.07	-0.12	-0.26	0.19	0.04	-0.27	-0.07	-0.06	0.09	-0.05		-0.23	0.07	-0.47	-0.49	-0.04
Turkey	-0.25	-0.21	-0.31	-0.14	-0.30	-0.27	-0.36	-0.51	-0.11	-0.27		-0.08	0.19	-0.20		-0.05
Vietnam	0.04	0.00		0.12	0.24	-0.12	-0.08	0.11	-0.07	-0.08		-0.05	-0.19	-0.01	0.02	-0.03

Score Difference -0.7 -0.4 -0.1 0.1 0.4 0.7

This heat map allows for a reading of India's performance in the EAPI in relative terms. It provides a sense of the distance in scores that separates India from other members of the Grow archetype. Blue-shaded cells and grey-shaded cells indicate that India scores or ranks respectively higher or lower than the comparator, while no shading means that there is no significant divergence. The darker the shading, the greater the difference in performance.

4. Access

Economic Growth and Development	GDP per capita		HDI index		Import bill as a share of GDP		Energy intensity		Share of mineral products in export	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Bangladesh	0.02	992.12	0.11	0.46	0.87	0.03	0.76	0.14	0.99	1.22
Benin	0.03	1272.6	0.06	0.43			0.41	0.25	0.46	46.61
Cambodia	0.03	1304.6	0.17	0.49	0.75	0.05	0.57	0.20	0.96	3.78
Ethiopia	0.01	561.97	0.00	0.32	0.59	0.08	0.00	0.51	1.00	0.45
Ghana	0.02	1114.4	0.12	0.46	0.28	0.14	0.25	0.30	0.95	4.70
Haiti	0.02	982.18	0.02	0.41	0.58	0.09	0.39	0.26	0.91	8.08
Kenya	0.03	1255.8	0.12	0.46	0.40	0.12	0.22	0.31	0.93	6.10
Mongolia	0.07	2612.7	0.41	0.62	0.05	0.19	0.12	0.34	0.10	78.47
Nepal	0.02	912.26	0.04	0.42	0.59	0.08	0.15	0.33	0.98	2.10
Tanzania	0.02	986.27			0.59	0.08	0.00	0.39	0.81	16.71
Togo	0.01	759.69	0.05	0.42	0.29	0.14	0.00	0.49	0.78	19.30

Environmental Sustainability	Carbon intensity		Share of non-carbon energy		Outdoor air pollution		Freshwater withdrawals	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Bangladesh	0.64	0.73	0.02	0.45	0.00	133.57		
Benin	0.67	0.68	0.00	0.00	0.55	44.91		
Cambodia	0.77	0.51	0.00	0.08	0.59	41.22	0.92	3.38
Ethiopia	0.85	0.38	0.05	0.93	0.38	58.93		
Ghana	0.73	0.57	0.29	5.63	0.79	24.48	0.92	3.24
Haiti	0.80	0.45	0.03	0.58	0.66	35.37	0.78	9.22
Kenya	0.77	0.50	0.35	6.99	0.73	30.00		
Mongolia	0.00	2.52	0.00	0.00	0.00	111.45	0.97	1.44
Nepal	0.86	0.35	0.14	2.69	0.71	31.68	0.88	5.08
Tanzania	0.83	0.40	0.06	1.20	0.83	21.66		
Togo	0.36	1.22	0.02	0.31	0.74	29.16		

Energy Access and Security	Import dependence		Quality of electricity supply		Solid fuel use		Diversity of supply	
Country	KPI	Raw	KPI	Raw	KPI	Raw	KPI	Raw
Bangladesh	0.35	16.28	0.00	1.89	0.00	89.72	0.71	0.62
Benin	0.26	39.00	0.08	2.36	0.00	94.28	0.46	0.47
Cambodia	0.29	30.31	0.11	2.52	0.00	90.97	0.38	0.42
Ethiopia	0.39	6.70	0.39	3.88	0.00	95.00	0.00	0.14
Ghana	0.30	27.50	0.26	3.23	0.00	85.88	0.47	0.48
Haiti	0.30	28.27			0.00	93.04	0.37	0.41
Kenya	0.35	16.16	0.36	3.72	0.02	75.00	0.32	0.38
Mongolia	0.52	-23.41	0.19	2.89	0.00	76.75	0.42	0.44
Nepal	0.37	10.88	0.00	1.71	0.00	82.00	0.09	0.24
Tanzania	0.39	7.84	0.07	2.29			0.04	0.21
Togo	0.35	16.58			0.00	95.00	0.11	0.26

This heat map allows for a reading of Ghana's performance in the EAPI in relative terms. It provides a sense of the distance in scores that separates Ghana from other members of the Access archetype. Blue-shaded cells and grey-shaded cells indicate that Ghana scores or ranks respectively higher or lower than the comparator, while no shading means that there is no significant divergence. The darker the shading, the greater the difference in performance.

Country	**Economic growth & development**	GDP per capita	HDI	Import bill as a share of GDP	Energy intensity	Share of mineral products in export	**Environmental sustainability**	Carbon intensity	Share of non-carbon energy	Outdoor air pollution	Freshwater withdrawals	**Energy access & security**	Import dependence	Quality of electricity supply	Solid fuel use	Diversity of supply
Ghana	**0.31**	**0.02**	**0.12**	**0.28**	**0.25**	**0.95**	**0.68**	**0.73**	**0.29**	**0.79**	**0.92**	**0.26**	**0.30**	**0.26**	**0.00**	**0.47**
Bangladesh	-0.26	0.00	0.00	-0.59	-0.51	-0.04	0.46	0.09	0.26	0.79		-0.01	-0.05	0.26	0.00	-0.24
Benin	0.06	0.00	0.06		-0.16	0.49	0.28	0.06	0.29	0.24		0.06	0.05	0.17	0.00	0.01
Cambodia	-0.19	-0.01	-0.06	-0.47	-0.32	-0.01	0.11	-0.04	0.28	0.20	0.00	0.06	0.01	0.14	0.00	0.09
Ethiopia	0.03	0.02	0.12	-0.32	0.25	-0.05	0.26	-0.11	0.24	0.41		0.06	-0.09	-0.13	0.00	0.47
Haiti	-0.07	0.00	0.10	-0.30	-0.14	0.04	0.12	-0.07	0.26	0.13	0.14	0.03	0.00		0.00	0.10
Kenya	-0.01	0.00	0.00	-0.12	0.03	0.02	0.07	-0.04	-0.07	0.07		0.00	-0.05	-0.10	-0.02	0.15
Mongolia	0.17	-0.04	-0.29	0.23	0.13	0.86	0.44	0.73	0.29	0.79	-0.04	-0.02	-0.21	0.07	0.00	0.05
Nepal	-0.02	0.01	0.08	-0.31	0.10	-0.03	0.04	-0.13	0.15	0.09	0.04	0.14	-0.07	0.26	0.00	0.38
Tanzania	-0.02	0.00		-0.31	0.25	0.14	0.11	-0.10	0.22	-0.03		0.09	-0.08	0.19		0.43
Togo	0.12	0.01	0.07	-0.01	0.25	0.17	0.31	0.37	0.27	0.06		0.10	-0.05		0.00	0.36

Score Difference -0.7 -0.4 -0.1 0.1 0.4 0.7

Appendix D: Robustness Tests Conducted on the Energy Architecture Performance Index

Weight Simulation – Robustness test of the Index based on multiple weight simulations on dependent variables

Weight simulation involves assigning different weights to the dependent variables, and then comparing the simulated score of the index computed for each combination of assigned weights, with the original score of the index can indicate the robustness of the index.

Weights were assigned to each dependent variable distributed randomly for 1,200 trials, and a simulated score of the index was calculated for each trial. Finally, the median of the 1,200 simulated scores of the index was computed. Overall, the median score of the simulated index was very close to the original score of the sub-indices, indicating that the indices are robust.

Hypothesis Testing – Whether samples drawn randomly from the index significantly differ from the index or not, in statistical terms

This test assesses whether a sample drawn randomly from a population differs significantly from the population itself, as a means by which to confirm that the characteristics of the population are robust or not. For the three sub-indices, 36 trials were conducted, each drawing random samples of 10 countries from a sub-index. These trials tested the following Null Hypothesis:

- Null Hypothesis: Sample mean = Index mean
- Level of significance: 95%
- Condition: If{ Critical Value < t < Critical Value} , Accept Null Hypothesis

To assess the null hypothesis a Student's t-Test (a way of testing means of arrays with unequal variances in a two-tailed test) was completed on each of the random samples. Thirty-six trials were conducted, of which 34 accepted the Null Hypothesis, indicating the robustness of the index.

Correlation Analysis – Robustness of the index with respect to its linear dependence on its variables

A correlation analysis indicates whether there is a linear relationship between the index and its dependent variables. This is tested by computing the Pearson's Correlation Coefficient between the final score of the index and the raw values of its dependent variables. The coefficient tests the strength of the linear dependence between the index and its variables, represented by a value between -1 to 1. The value of the coefficient, which is away from zero, indicates a well-correlated relationship between the index and its variable. The results for the sub-indices ranged from a mild to healthy correlation between them and their dependent variables.

Sensitivity Analysis – Testing the variation in the output that can be attributed to different variations in the inputs

Testing the variation in the final index score as a result of assumed variation levels of the dependent variables, reveals the sensitivity of the index to small and large variation in the dependent variables. This is tested by applying a variation of -30% to +30% in intervals of 10%, to each dependent variable of a sub-index at the country-level, and finally, re-computing the final score of the index with the new value of the dependent variable. The variation of the new score from the original score indicates the sensitivity of the index. The impact on the final score of the index as a result of the sensitivity analysis remained low, ranging from -10% to +10%, on application of a +/-30% variation on the dependent variables. This indicates that the index is robust and has a capacity to absorb large variation in the dependent variable.

Acknowledgements

Steering Board Members

Samir Brikho, Chief Executive Officer, AMEC, United Kingdom

Juan Carlos Castilla-Rubio, Managing Director, Global Resources Innovation Group, Cisco, Brazil; Chief Executive Officers, Planetary Skin Institute

Bob G. Elton, Executive Chair, Powertech Labs, Canada

Simon Henry, Chief Financial Officer, Royal Dutch Shell, Netherlands

Jim Kelly, Global Head of Energy Efficiency, ABB, Switzerland

Lee McIntire, Chairman and Chief Executive Officer, CH2M Hill Companies, USA

Christine Ramon, Executive Director and Chief Financial Officer, Sasol, South Africa

Vijay Vaitheeswaran, China Business, Finance, Tech Editor and Shanghai Bureau Chief, The Economist, USA

Rhonda I. Zygocki, Executive Vice-President, Policy and Planning, Chevron Corporation, USA

Task Force Members

Manpreet Anand, Senior Policy Advisor, Chevron Corporation, USA

Juergen Arnold, Chief Technology Officer, Enterprise Servers, Storage and Networking, Hewlett-Packard, Germany

Gabriel Barta, Head of Technical Coordination, International Electrotechnical Commission, Geneva

Claus Beckmann, Manager, Environment and Energy, Government Relations, BASF

David Elzinga, Energy Technology Analyst, International Energy Agency, Paris

Wes Frye, Managing Director, Sustainable Energy Innovations, Cisco Systems, USA; Chief Development Officer (Energy) for Planetary Skin Institute

Kanv Garg, Consultant, Expert Group on Low Carbon Economy, Planning Commission, Government of India

Anant Gupta, President, HCL Technologies Infrastructure Services Division, India

Peter T. Gutman, Global Head, Renewable Energy and Environment Finance, Standard Chartered, United Kingdom

Ivan Huang, Senior Marketing Manager, Huawei Technologies, People's Republic of China

David Johnson, Executive Vice-President and President, Europe, Africa and Middle East, Nalco Europe B.V., Netherlands

Barbara Judge, Chairman, United Kingdom Atomic Energy Authority, United Kingdom

Ma Lingjuan, Deputy Managing Director, Renewable Energy and Energy Efficiency Partnership (REEEP), East Asia Regional Secretariat, Chinese Renewable Energy Industries Association (CREIA), People's Republic of China

Andrei Marcu, Senior Vice-President, Head of Regulatory Affairs and Policy Affairs, Mercuria Energy Group, Switzerland

Eric Martinot, Lead Author and Research Director, REN21 Renewable Energy Policy Network; Senior Research Director, Institute for Sustainable Energy Policies, Japan

Steve Mercieca, Project and Export Finance, Middle East, Africa & Pakistan, Standard Chartered, United Kingdom

Wendy Poulton, General Manager, Strategy and Risk Management, Eskom

Kwok Shum, Professor, Akio Morita School of Business, USA

Alexander Tolkach, Director, External Affairs, DTEK, Ukraine

Fleming Voetmann, Director, Head of Public Affairs and Media Relations, Novozymes, Denmark

Molly Webb, Head of Strategic Engagement, Climate Group, United Kingdom

Lorie Wigle, General Manager, Eco-Technology Program Office, Intel Corporation, USA

World Economic Forum

Roberto Bocca, Senior Director, Head of Energy Industries

Espen Mehlum, Associate Director, Head of Knowledge Management and Integration Energy Industries

Project Adviser: Accenture

Arthur Hanna, Managing Director, Energy Industry

James Collins, Senior Manager, Energy Strategy

Mike Moore, Project Manager, New Energy Architecture, Accenture Secondee

Timothy Hendrikz, Analyst, Energy Strategy

Further support: Bryan Hori, Philbert Hakim, Rena Rzaeva, Samuel Madden, Jenny Hawes-Hewitt, Pete Thompson, Kyoko Hiraoka, Adam Perkins, Abhinav Mehrishi, Gururaj Rao, Simon Giles, Mark Purdy, Ian O'Gara and Mauricio Bermudez Neubauer

Design

Kamal Kimaoui, Director, Head of Production and Design, World Economic Forum

Floris Landi, Graphic Designer, World Economic Forum

Rob Cubbon, Rob Cubbon Ltd.

COMMITTED TO
IMPROVING THE STATE
OF THE WORLD

The World Economic Forum is an independent international organization committed to improving the state of the world by engaging business, political, academic and other leaders of society to shape global, regional and industry agendas.

Incorporated as a not-for-profit foundation in 1971 and headquartered in Geneva, Switzerland, the Forum is tied to no political, partisan or national interests.

World Economic Forum
91–93 route de la Capite
CH-1223 Cologny/Geneva
Switzerland

Tel.: +41 (0) 22 869 1212
Fax: +41 (0) 22 786 2744

contact@weforum.org
www.weforum.org