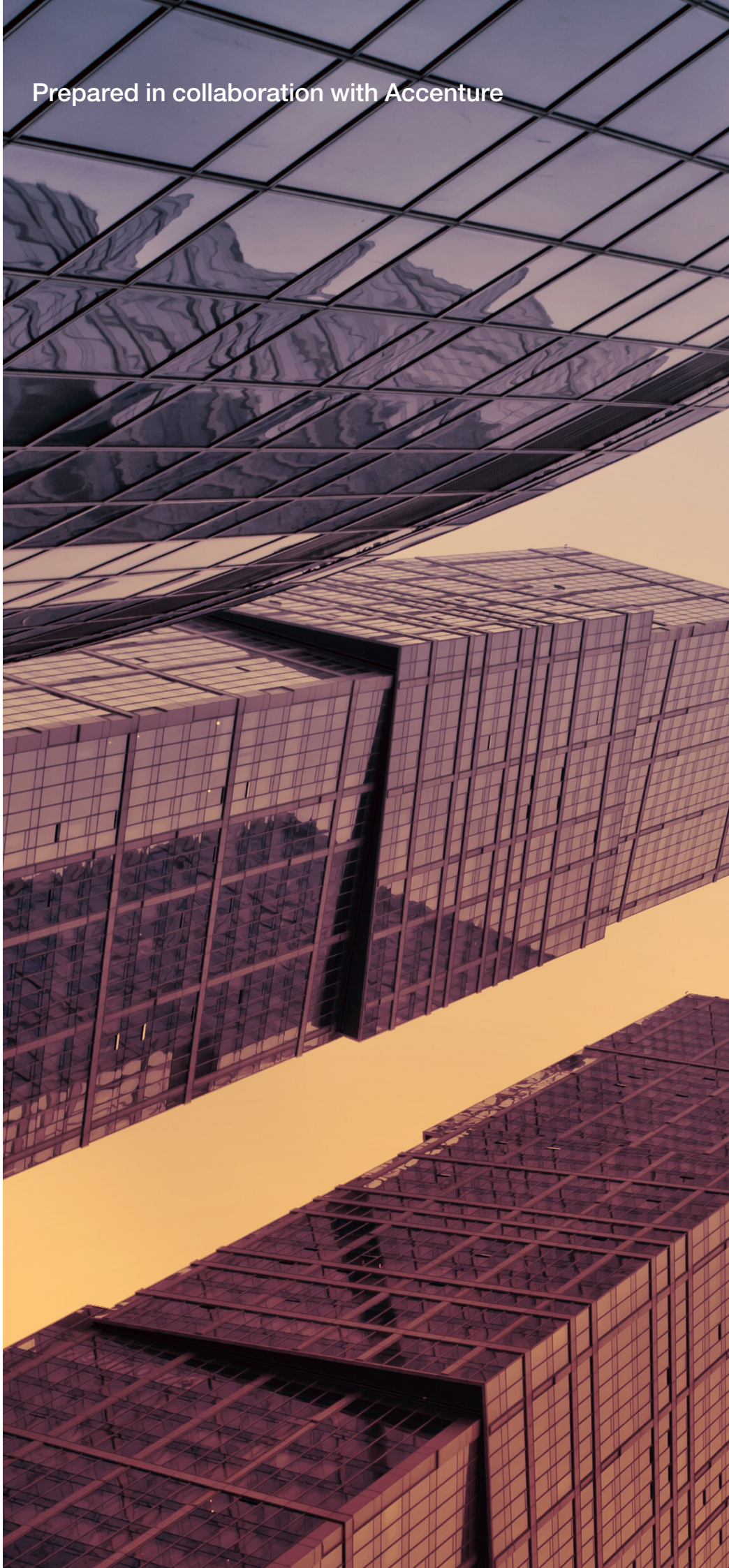
WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

Industry Agenda

Global Energy Architecture Performance Index Report 2016

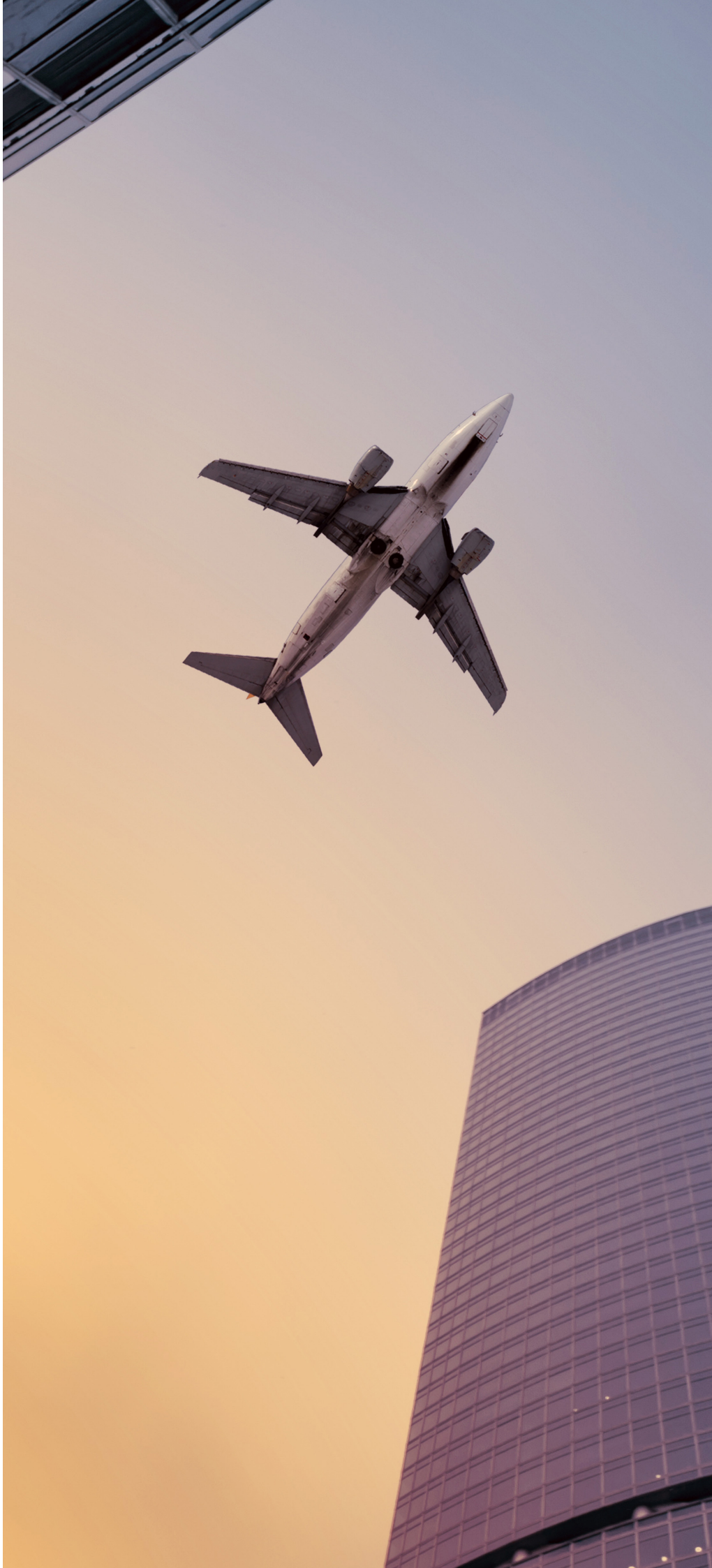
Prepared in collaboration with Accenture



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
Email: contact@weforum.org
www.weforum.org

REF 161215

Contents



Acknowledgements

The World Economic Forum is pleased to acknowledge and thank the individuals and partners listed here, without whom the creation of the global Energy Architecture Performance Index 2016 would not have been possible.

Project Adviser: Accenture

Arthur Hanna, Senior Managing Director, Energy, Accenture Strategy
James Collins, Managing Director, Energy Strategy, Accenture
Mike Moore, Project Adviser, New Energy Architecture
Olivier Queinnec, Lead Author, Accenture Strategy & Sustainability
Additional acknowledgements: Maria Agostini, Ash Kebriti, Mwenya Kawesha, Fergal Madigan, Jenna Trescott and Marcello Deplano

Chief Expert Advisers

Morgan Bazilian, Lead Energy Specialist, World Bank
David Victor, Professor of International Relations and Director, Laboratory on International Law, University of California, San Diego; Chair, Global Agenda Council on Governance for Sustainability
Giuseppe Montesano, Head, European Energy Policies and Analysis, Enel
Eirik Wærness, Chief Economist and Vice-President, Statoil

Data Partners

International Energy Agency (IEA), German Federal Enterprise for International Cooperation (GIZ), World Bank Group (WBG), World Trade Organization (WTO), UN SE4ALL, UN Stat division and UNCTADstat

World Economic Forum

Roberto Bocca, Head of Energy Industries, Member of the Executive Committee
Espen Mehlum, Head of Knowledge Management and Integration, Energy Industries (Project Lead)
Thierry Geiger, Head of Analytics and Quantitative Research, Global Competitiveness and Risks
Khalid Al-Ahmed, Manager, Knowledge Integration, Energy Industries
Additional acknowledgements: Anja Kaspersen

Foreword

Roberto Bocca
Head of Energy Industries
Member of the Executive Committee
World Economic Forum

Arthur Hanna
Senior Managing Director
Energy
Accenture Strategy

The year in energy

Over the past year, global conditions have continued to challenge the energy sector. The year has seen changes in energy prices and production, a slowdown in the growth of emerging economies, and geopolitical instability, which effectively reshuffled energy demand and supply scenarios. Both man-made and natural disturbances exacerbate difficulties in predicting the future supply-demand balance as well as the governance of energy resources.

In last year's index report, we highlighted three trends across the pillars of what we call the "energy triangle":

1. **Economic growth and development:** The drop in oil prices impacting economic growth
2. **Environmental sustainability:** Ambitious pledges redefining national emissions pathways
3. **Energy security and access:** Energy access and security remaining captive to geopolitical tensions in key producing regions

This year can be characterized as a continuation of the same themes. However, the way in which these themes have played out has been both remarkable and unforeseen.

Economic growth and development

Low energy and oil prices, an important theme in the 2015 report, have further impacted economic growth and development. Oil prices this past year were last seen six years ago during the global financial crisis. Supply has consistently outstripped demand by about 1.5 million barrels

of oil per day, as the battle over market share between unconventional oil producers and OPEC countries helped to push world oil supply above the levels at the end of last year by approximately the same amount (1). According to Kenneth Rogoff, Thomas D. Cabot Professor of Public Policy and Professor of Economics, Harvard University, USA (whose insights are included in this report), the current steady low prices should not deter preparation for more volatile prices in the future. Key producers are estimated to have cut over $200 billion in capital expenditure on new projects, deferring oil and gas projects connected to reserves that equate to 20 billion barrels of oil (2).

Environmental sustainability

Emissions pledges have evolved into Intended Nationally Determined Contributions (INDCs) in advance of the 21st Conference of the Parties, and include a range of proposed commitments, such as quantified emission reduction targets, renewable energy targets and related action areas, including carbon capture and storage and sustainable transport (3). In this year's global Energy Architecture Performance Index (EAPI), we observe remarkable progress in renewable energy, now established as the dominant technology used when expanding electricity production capacity or when replacing outdated generators. Renewables accounted for an estimated 59% of net electric capacity additions in 2014 (4), and the ratio between renewables and traditional energy sources for electricity production is expected to reach 3 to 1 within 15 years (5).

Energy security and access

The geopolitical tensions we explored last year have since evolved; recent events and longer-term developments have had a powerful impact on energy security and access. ISIS has forged a reputation as a non-state threat to energy security after taking control of key oil and gas assets in Iraq and Syria, and expanding into a broader, international terrorist threat. ISIS is estimated to produce more oil in Syria than non-ISIS Syrian assets, generating estimated daily revenues of over $1 million (6). This past year, we have also seen the threat extend beyond conventional means, as a number of alleged cyberattacks against the US energy grid highlighted the growing risk that non-state players could pose to energy security (7). Finally, energy access figures, as reported in the World Bank's Global Tracking Framework, showed a modest improvement in terms of electricity access.

The stage has been set for a fundamental reshaping of energy systems and associated infrastructure, a subject discussed extensively in this report. Scattered signs of progress are evident. Pressure has mounted on stakeholders to deliver tangible environmental outcomes following the United Nations Conference on Climate Change in Paris, and potential relief from US and European Union (EU) sanctions could diversify Iran's energy supply. Many countries have started to phase out or reduce fossil-fuel subsidies and to undertake broader energy reforms. However, at this pivotal juncture for the energy sector, effective collaboration between stakeholders will be critical for developing a sustainable approach to meeting the world's future energy needs.

Ambition of the Energy Architecture Performance Index

The Energy Architecture Performance Index, developed by the World Economic Forum in collaboration with Accenture, is now in its fourth year. Since it was launched, the EAPI has contributed to the global benchmarking of energy systems, highlighting topical energy issues and providing guidance on making energy transitions more effective. This year's report includes the findings from benchmarking 126 countries on 18 indicators covering energy security and access, sustainability, and contribution to economic growth and development. For the first time, EAPI results have been compared with a benchmark (2009), enabling trend analysis over a seven-year period.

Like any index, the EAPI cannot fully reflect the complexity of energy systems or of managing energy transitions. It can, however, serve to benchmark the performance of national energy systems, providing a basis for comparison across nations. The EAPI offers the latest available global energy data, aiding policy formation by providing a reliable indicator of strengths and target areas for improvement.

This report also includes a special chapter focusing on how the energy security landscape is changing and the implications thereof. As the energy sector's transition unfolds faster than ever, and as conditions influencing energy evolve (such as the international security landscape and digital transformation) the time is ripe for a fresh look at energy security, one of the three core dimensions of the EAPI. How are the factors influencing energy security changing? What are the implications for governments and companies? This report is designed to help the reader think through these pertinent questions, with the EAPI providing a fact-based framework to support the discussion.

Executive summary

The results of the global Energy Architecture Performance Index 2016 (EAPI) reveal strengths and weaknesses across regions, as major economies struggle to take leading positions in the EAPI:

- The analysis of this year's top performers shows no clear-cut "winners" or perfect energy architectures. The strong scores of the top performers (with **Switzerland 1st** overall) reveal balance across the energy triangle, but significant room for improvement remains. **Norway (2nd)**, for example, has nearly the maximum score for energy security but lags behind some countries in environmental sustainability and in contribution to economic growth.
- High-performing countries are not confined to a single region. The EAPI points to the strengths of countries beyond the usual suspects. For example, **Albania (17th)** and **Paraguay (21st)** boasted fully decarbonized electricity generation (0 grams of carbon dioxide per kilowatt-hour [gCO_2/kWh]), which is reflected in above-average environmental sustainability scores.
- Low oil prices are forcing or accelerating subsidy reforms to restore fiscal balance in countries reliant on oil revenues such as **Mexico (49th)** and the **United Arab Emirates (UAE) (104th)**.
- The world's largest economies still struggle to achieve balanced high performance in their energy systems. With the exception of **France (4th)**, none of the 12 largest countries by gross domestic product made it into the top 10 performers. Many of the major economies actually rank somewhat low in the index, with half not making it into the top 40.

Diversification to new energy sources is creating new risks and opportunities that will require significant market change and government mechanisms to ensure security of supply and access:

- Expansion of primary energy sources is demonstrated by year-over-year improvements in EAPI scores for diversification of energy supplies in many countries. Denmark, for example, has improved supply diversity by 15%.
- The trend is driven, in part, by expansion of renewable energy sources, which offer countries low and stable operating costs. Several advanced economies, including Austria, Finland, Denmark, Portugal, Germany and France, are leading the energy transition to alternative and renewable energy sources. Globally, renewable electric power capacity has skyrocketed by approximately 650% this past decade (4) to account for approximately 6% of generation (8).
- As a result, new opportunities and challenges are emerging for energy security. However, a successful transition will require market transformation and significant changes to the electric utility business model and regulatory policies.
- Progress in expanding distributed renewable energy is opening up promising avenues for providing access to electricity in previously deprived areas.

While digital disruption will lead to new complexities in energy security, an increasingly interconnected and technologically sophisticated global energy system will also introduce new benefits:

- Big data can mitigate traditional risks by pinpointing areas of risk and vulnerability, and digital technologies are helping to decentralize and manage energy architectures. Utilities are therefore rapidly adopting big data, and expect to spend $37 billion on consumer data tools over the next eight years (9).
- The convergence of digital and physical infrastructure, led by connected devices, robotics and the Industrial Internet of Things, could see over 7 billion devices installed across

the energy value chain by 2020. This convergence is also creating new forms of insight and control that can enhance energy security (10).

– However, despite numerous benefits, new capabilities are required to manage a more complex, interconnected energy system, requiring new investment in capabilities for risk protection.

A new distribution of powers and energy trade flows – a new global energy security order – will create challenges and opportunities:

– The emergence of giant economies in Asia, accounting for 35% of fuel trades in 2014 (up from 20% in 2004), and unconventional oil production in North America, which has added over 8 million barrels per day to the market (11), have led to a rebalancing of supply, demand and power around the world.

– More actors are becoming relevant – non-state organizations, individual citizens, corporations and new coalitions – which could strengthen or threaten international security arrangements.

As major forces prompt transformations across global energy systems, governments and industry together play critical roles in achieving successful energy transitions:

– Governments will need to be receptive to new opportunities and risks to energy security resulting from developments in the energy sector, surrounding technology and international landscape. Governments should ultimately take responsibility for ensuring energy security in the short and long term.

– Companies play a critical role because investors, owners and operators of energy infrastructure will be essential to reaping the benefits of new technologies. This will ensure having affordable and secure supplies of energy and building safeguards against rising threats, such as cybersecurity.

– New approaches to governance for physical and technological estates will be required, creating a need for increased collaboration between operators, policy-makers, and national and international entities with capabilities to tackle new digital and physical security threats.

Kenneth Rogoff
Professor of Public Policy and Professor of Economics, Harvard University

Perspective: Macroeconomic implications of the sharp 2014-2015 drop in oil prices

The stunning fall in the price of oil, from a peak of $115 per barrel in June 2014 to under $45 end November 2015, has been one of the most important global macroeconomic developments of the past 18 months. The sharp fall is similar in magnitude to the decline in 1985-1986, when OPEC members reversed earlier production cuts, and in 2008-2009 at the outset of the global financial crisis. Understanding the underlying causes of price drops is essential to interpreting their macroeconomic effects. The 1985-86 decline was mainly supply-driven, while the drop in 2008-2009 was almost entirely due to a collapse in demand. The recent price decline appears to be a mix of the two.

Slowing growth in emerging markets, most importantly in China, has led to sharp drops in commodity prices almost across the board. The drop in oil prices, however, has been significantly steeper than in metals and food. The magnitude of the differential is one important metric that suggests that rising supply has been at least as important as falling demand; most mainstream macroeconomic models suggest that the effect on global GDP has been on the order of 0.5%. This is significant, but less than past experience might have suggested, though the effect may prove larger if the decline persists.

There appear to be three reasons for this lower impact on global GDP. First, although the oil price decrease has been largely passed on to consumers in advanced countries, there has been much less pass-through in the rest of the world. Many governments – for example, in China and India – have taken advantage of the decline to reduce subsidies on fuel consumption and thereby strengthen their fiscal position. A second reason is that, normally, a supply-driven oil price decline raises world demand by transferring resources from high-saving oil producers to consumers with a higher propensity to spend. This channel, however, has been muted, as major oil producers have faced pressures to increase spending, and as consumer countries continue to repair balance sheets from the financial crisis. Third, the collapse in oil prices has led to a major short-term drop in investment in the oil industry, with global investment in production and exploration falling from $700 billion in 2014 to $550 billion in 2015, with spill-over to energy commodities. Sharp declines in investment in other commodity sectors have also contributed to overall slow global growth.

There is no question that the oil price decline has been a significant contributor to the financial market volatility of the last year. Can the impact worsen? A primary concern is that there could be a cycle of deteriorating financing conditions for oil companies and oil exporters. Countries that are heavily dependent on remittances from citizens working in oil economies are also at risk. So far, exchange rate flexibility and (for some countries) a large cushion of hard currency reserves have helped significantly in avoiding an outright financial crisis. But if the low price is sustained, important oil producers may become increasingly vulnerable if they are unable to make the requisite fiscal adjustments to a lower price trajectory. Over the longer term, it is important for oil exporters to diversify their economies and sources of fiscal revenue in order to decrease vulnerability to oil price volatility.

For oil-importing countries, the price decrease is a welcome stimulus for advanced economies, and provides an opportunity to strengthen fiscal resilience against capital outflows for many emerging markets. However, it is important for policy-makers to continue policies that strengthen the long-term growth potential of their economies. Although futures prices suggest that oil prices will rise only moderately over the next four years, it is important to prepare for the fact that oil prices can rise in the future just as sharply and unexpectedly as they have fallen in the past.

Energy architecture performance index methodology

Background

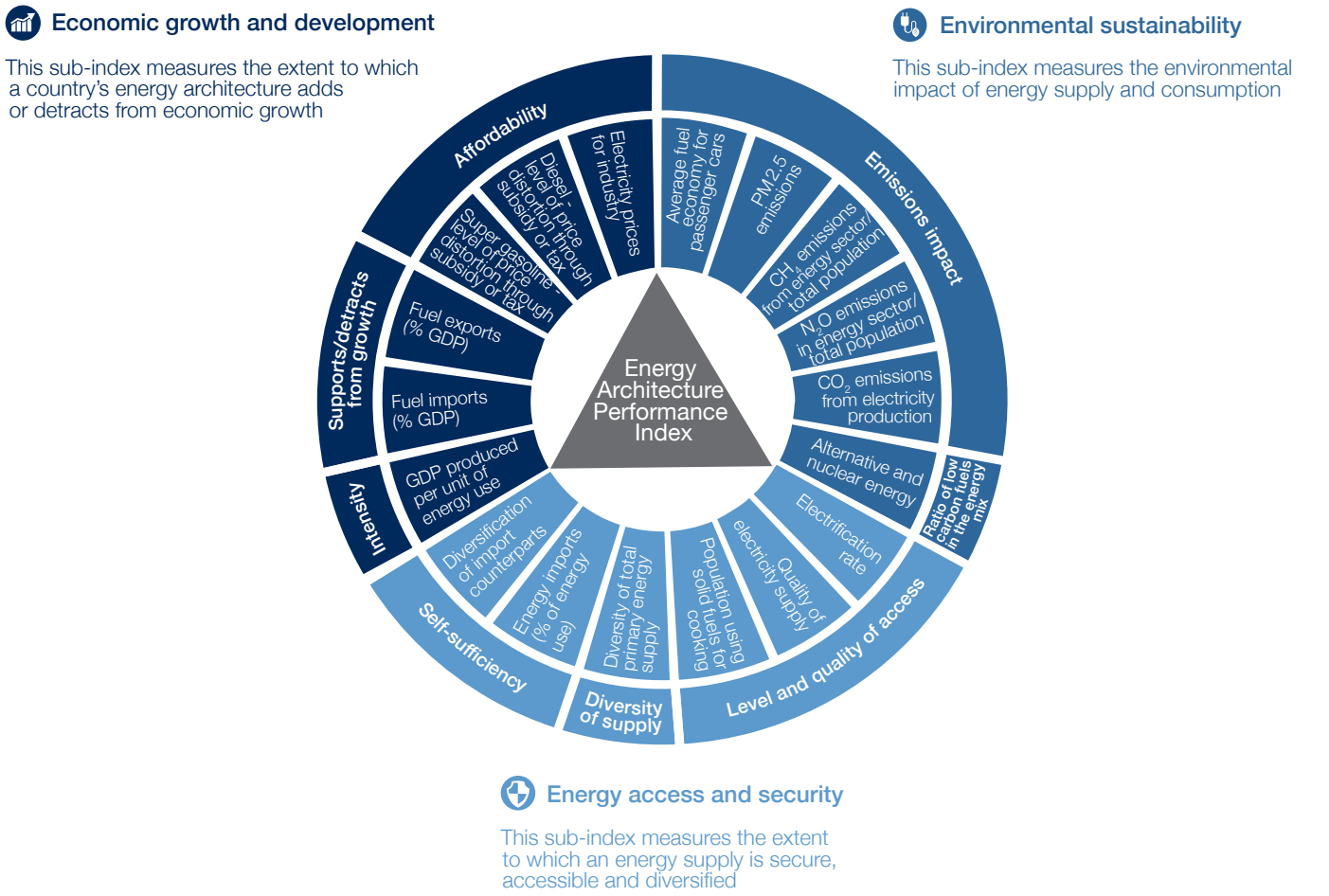
Since 2013, the EAPI has provided a tool for decision-makers to help better understand energy systems, and to assess the current energy architecture performance of individual nations.

Methodology

The EAPI is a composite index that focuses on tracking specific indicators to measure the energy system performance of 126 countries.[1] At its core are 18 indicators defined across each side of the "energy triangle": economic growth and development, environmental sustainability, and energy access and security (Figure 1).

Scores (on a scale of 0 to 1) and associated rankings are calculated for each of these indicators. These are then aggregated based on defined weights to calculate a score and ranking for each sub-index and for the EAPI overall. A methodological addendum on the EAPI can be found in the appendices on page 33 and the full methodology is available online at http://wef.ch/eapimethodology.

Figure 1: The energy architecture performance index and its indicators



Source: World Economic Forum and Accenture analysis

[1] The index now includes Cuba, Sudan and Zimbabwe; however, it no longer includes Syria and Macedonia, FYR, due to a lack of data

EAPI 2016 results

Figure 2: The energy architecture performance index 2016 ranking

Economic growth and development
Environmental sustainability
Energy access and security

	Country	2016 score[2]				2009-16 trend[3]
1	Switzerland	**0.79**	0.72	0.76	0.88	▲ (+1)
2	Norway	**0.78**	0.65	0.74	0.95	▼ (-1)
3	Sweden	**0.76**	0.61	0.80	0.89	▲ (+1)
4	France	**0.76**	0.60	0.80	0.88	▼ (-1)
5	Denmark	**0.76**	0.67	0.70	0.91	▲ (+1)
6	Austria	**0.75**	0.64	0.74	0.88	▲ (+3)
7	Spain	**0.75**	0.65	0.74	0.87	▲ (+5)
8	Colombia	**0.75**	0.74	0.67	0.84	▲ (+3)
9	New Zealand	**0.75**	0.59	0.75	0.90	▲ (+4)
10	Uruguay	**0.74**	0.69	0.73	0.81	▲ (+16)
11	Portugal	**0.73**	0.60	0.74	0.85	▲ (+3)
12	Finland	**0.73**	0.53	0.78	0.87	▼ (-5)
13	Costa Rica	**0.73**	0.68	0.76	0.75	▼ (-3)
14	Latvia	**0.71**	0.61	0.72	0.81	▲ (+4)
15	Slovenia	**0.71**	0.56	0.72	0.87	▲ (+5)
16	United Kingdom	**0.71**	0.60	0.66	0.89	▼ (-1)
17	Albania	**0.71**	0.65	0.80	0.69	▲ (+17)
18	Croatia	**0.71**	0.63	0.67	0.82	▲ (+13)
19	Hungary	**0.70**	0.58	0.73	0.81	▲ (+14)
20	Peru	**0.70**	0.75	0.65	0.70	▼ (-1)
21	Paraguay	**0.70**	0.66	0.81	0.63	▲ (+2)
22	Italy	**0.70**	0.58	0.67	0.84	▲ (+2)
23	Ireland	**0.70**	0.64	0.65	0.80	▲ (+2)
24	Germany	**0.70**	0.58	0.63	0.87	▼ (-8)
25	Brazil	**0.69**	0.59	0.70	0.79	▼ (-17)
26	Iceland	**0.69**	0.36	0.90	0.81	▼ (-9)
27	Romania	**0.69**	0.63	0.67	0.77	▲ (+14)
28	Slovak Republic	**0.69**	0.52	0.73	0.82	▲ (+4)
29	Congo, Rep.	**0.69**	0.76	0.76	0.55	▲ (+1)
30	Canada	**0.69**	0.57	0.61	0.88	▼ (-2)
31	Czech Republic	**0.68**	0.55	0.62	0.88	▲ (+7)
32	Azerbaijan	**0.68**	0.68	0.57	0.79	▲ (+15)
33	Luxembourg	**0.68**	0.68	0.62	0.75	▲ (+6)
34	Belgium	**0.68**	0.49	0.72	0.83	▼ (-5)
35	Lithuania	**0.68**	0.57	0.71	0.76	▼ (-8)
36	Singapore	**0.68**	0.68	0.55	0.81	▲ (+1)
37	Netherlands	**0.68**	0.51	0.64	0.88	▼ (-16)
38	Chile	**0.67**	0.60	0.60	0.81	▲ (+18)
39	Argentina	**0.66**	0.68	0.59	0.72	▲ (+16)
40	Turkey	**0.66**	0.57	0.63	0.79	▲ (+4)
41	Poland	**0.66**	0.64	0.55	0.78	▲ (+2)
42	Panama	**0.66**	0.65	0.66	0.66	▼ (-2)
43	Greece	**0.66**	0.56	0.60	0.81	▼ (-8)
44	Bulgaria	**0.65**	0.54	0.66	0.76	▲ (+8)
45	Tajikistan	**0.65**	0.46	0.82	0.67	▲ (+21)
46	Georgia	**0.65**	0.48	0.75	0.71	▼ (-4)
47	El Salvador	**0.65**	0.51	0.72	0.71	▲ (+3)
48	United States	**0.64**	0.54	0.50	0.89	▲ (+5)
49	Mexico	**0.64**	0.59	0.60	0.74	▲ (+11)
50	Japan	**0.64**	0.53	0.56	0.84	▼ (-28)
51	Indonesia	**0.64**	0.56	0.64	0.71	▲ (+11)
52	Russian Federation	**0.64**	0.55	0.58	0.79	▼ (-16)
53	Australia	**0.64**	0.64	0.40	0.88	▲ (+8)
54	Sri Lanka	**0.64**	0.64	0.66	0.60	▲ (+4)
55	Korea, Rep.	**0.63**	0.55	0.52	0.84	▼ (-9)
56	Armenia	**0.63**	0.47	0.71	0.71	▲ (+1)
57	Kazakhstan	**0.63**	0.57	0.54	0.78	▲ (+2)
58	Israel	**0.63**	0.56	0.50	0.81	▼ (-10)
59	Morocco	**0.62**	0.54	0.57	0.75	▲ (+13)
60	Estonia	**0.62**	0.54	0.57	0.76	▼ (-9)
61	Philippines	**0.62**	0.56	0.63	0.67	▲ (+3)
62	Cuba	**0.62**	0.74	0.49	0.62	▼ (-17)
63	Tunisia	**0.61**	0.43	0.62	0.79	▼ (-14)

	Country	2016 score[2]				2009-16 trend[3]
64	Dominican Republic	**0.61**	0.62	0.56	0.64	▲ (+19)
65	Malta	**0.60**	0.64	0.56	0.61	▲ (+5)
66	Cyprus	**0.60**	0.58	0.57	0.65	▲ (+5)
67	Thailand	**0.60**	0.48	0.53	0.78	▲ (+8)
68	Namibia	**0.59**	0.57	0.74	0.46	▲ (+8)
69	Ecuador	**0.59**	0.49	0.60	0.68	▼ (-4)
70	Guatemala	**0.58**	0.46	0.73	0.56	▼ (-7)
71	Algeria	**0.58**	0.43	0.56	0.76	▼ (-17)
72	Ukraine	**0.58**	0.31	0.64	0.79	▲ (+6)
73	Nicaragua	**0.58**	0.44	0.72	0.58	▲ (+23)
74	Serbia	**0.58**	0.49	0.53	0.71	n/a
75	Ghana	**0.57**	0.59	0.69	0.43	▲ (+12)
76	South Africa	**0.57**	0.56	0.53	0.62	▲ (+10)
77	Zambia	**0.57**	0.49	0.89	0.33	▲ (+4)
78	Bolivia	**0.57**	0.39	0.59	0.72	▲ (+2)
79	Vietnam	**0.57**	0.42	0.59	0.69	▲ (+19)
80	Republic of Moldova	**0.57**	0.38	0.61	0.70	▲ (+9)
81	Cameroon	**0.57**	0.52	0.78	0.40	▼ (-8)
82	Libya	**0.55**	0.46	0.48	0.73	▼ (-15)
83	Egypt, Arab Rep.	**0.55**	0.42	0.52	0.71	▼ (-4)
84	Uzbekistan	**0.55**	0.42	0.56	0.66	n/a
85	Belarus	**0.54**	0.36	0.62	0.66	▼ (-11)
86	Honduras	**0.54**	0.39	0.71	0.54	▲ (+15)
87	Malaysia	**0.54**	0.32	0.49	0.82	▼ (-3)
88	Venezuela	**0.54**	0.32	0.61	0.68	▼ (-19)
89	Brunei Darussalam	**0.54**	0.45	0.43	0.73	▼ (-4)
90	India	**0.53**	0.51	0.49	0.61	▲ (+2)
91	Kenya	**0.53**	0.42	0.82	0.35	▼ (-3)
92	Sudan	**0.53**	0.43	0.77	0.39	n/a
93	Bosnia and Herzegovina	**0.53**	0.45	0.52	0.62	▼ (-3)
94	China	**0.53**	0.45	0.42	0.71	▲ (+1)
95	Zimbabwe	**0.53**	0.41	0.76	0.41	▼ (-2)
96	Kyrgyz Republic	**0.53**	0.22	0.74	0.61	▼ (-28)
97	Botswana	**0.53**	0.57	0.56	0.45	▼ (-3)
98	Jamaica	**0.52**	0.39	0.56	0.62	▲ (+19)
99	Iraq	**0.52**	0.53	0.29	0.75	n/a
100	Cote d'Ivoire	**0.52**	0.44	0.72	0.39	▼ (-23)
101	Mozambique	**0.51**	0.37	0.90	0.27	▼ (-10)
102	Cambodia	**0.51**	0.51	0.69	0.33	▲ (+14)
103	Pakistan	**0.51**	0.45	0.49	0.59	▲ (+9)
104	United Arab Emirates	**0.51**	0.45	0.28	0.80	▼ (-7)
105	Senegal	**0.50**	0.44	0.57	0.49	▼ (-2)
106	Bangladesh	**0.50**	0.63	0.43	0.45	▲ (+7)
107	Qatar	**0.50**	0.47	0.25	0.78	▼ (-8)
108	Nigeria	**0.49**	0.42	0.72	0.35	▼ (-26)
109	Mongolia	**0.49**	0.38	0.49	0.60	n/a
110	Trinidad and Tobago	**0.49**	0.35	0.42	0.70	▼ (-4)
111	Kuwait	**0.49**	0.46	0.18	0.83	▼ (-3)
112	Jordan	**0.49**	0.40	0.39	0.68	▲ (+6)
113	Oman	**0.48**	0.40	0.27	0.77	▼ (-13)
114	Saudi Arabia	**0.48**	0.40	0.21	0.82	▼ (-9)
115	Nepal	**0.48**	0.42	0.67	0.33	▼ (-4)
116	Togo	**0.47**	0.34	0.78	0.30	▲ (+5)
117	Iran, Islamic Rep.	**0.47**	0.30	0.36	0.76	▼ (-10)
118	Turkmenistan	**0.47**	0.29	0.35	0.77	▼ (-4)
119	Tanzania	**0.47**	0.39	0.78	0.23	▼ (-17)
120	Ethiopia	**0.45**	0.29	0.88	0.19	▼ (-5)
121	Benin	**0.44**	0.40	0.61	0.32	▼ (-1)
122	Eritrea	**0.44**	0.32	0.63	0.38	▼ (-18)
123	Haiti	**0.44**	0.41	0.69	0.23	▼ (-13)
124	Yemen, Rep.	**0.44**	0.59	0.32	0.40	▼ (-1)
125	Lebanon	**0.43**	0.38	0.39	0.53	▼ (-6)
126	Bahrain	**0.38**	0.16	0.24	0.73	▼ (-4)

Advanced economies
Emerging and developing Europe
Latin America and the Caribbean
Commonwealth of Independent States
Emerging and developing Asia
Sub-Saharan Africa
Middle East, North Africa and Pakistan

Note:
– EAPI 2016 methodology: see methodological addendum at the end of this Report
– Country scores are rounded to two decimal places, but exact figures are used to determine rankings. Therefore, countries with the same EAPI score may have different rankings

[2] EAPI 2016 score on scale from 0 to 1

[3] Change in ranking versus benchmark 2009

Summary of performance and findings

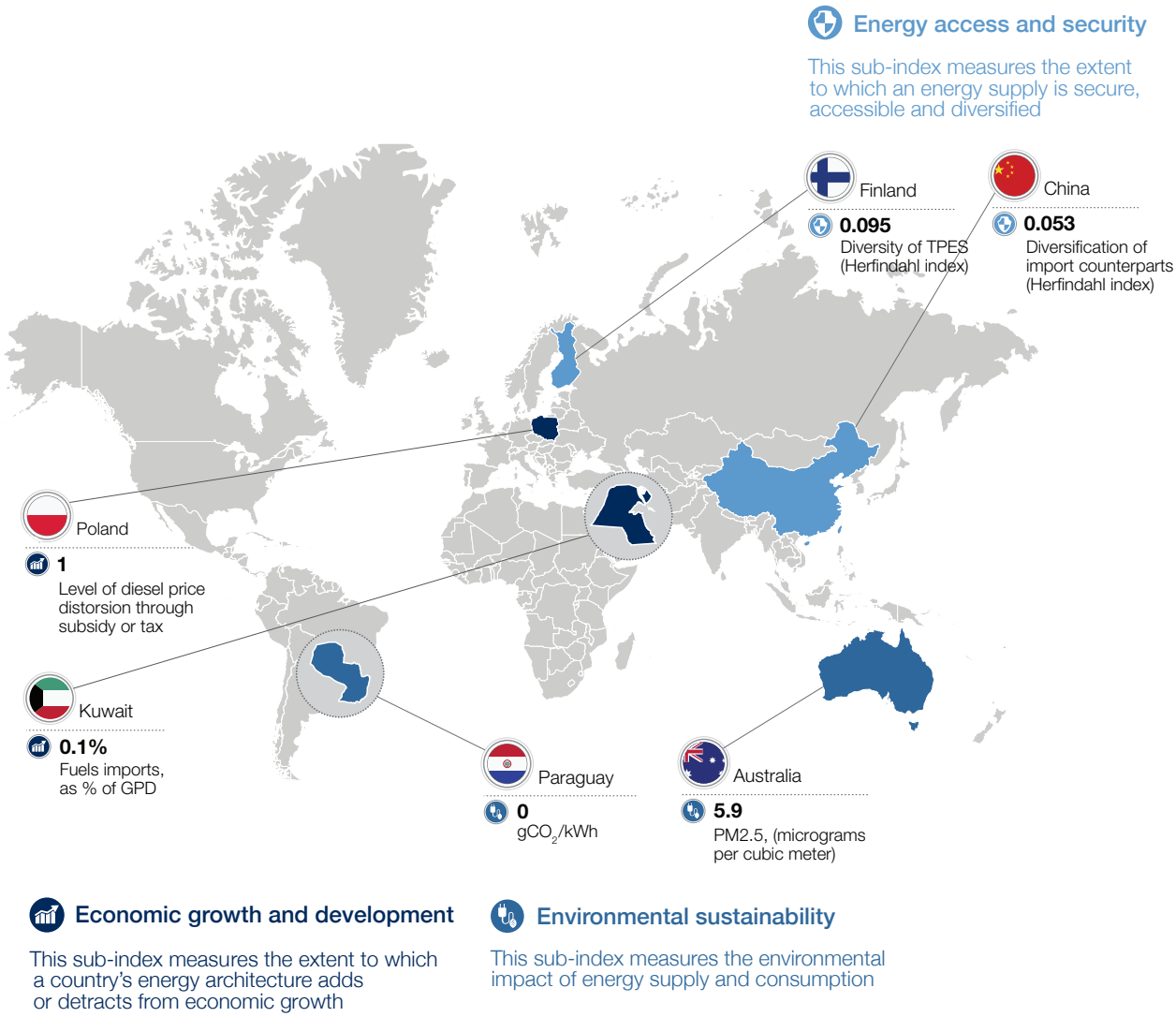
The following sections explore the key findings from this year's EAPI, with a focus on insights derived from an analysis of the trends in performance against 2009 data. This data was analysed, making use of the latest EAPI methodology (see the appendices) further referred to in this report as "Benchmark 2009". Energy transition takes time, but the analysis shows significant movement in the performance of countries from 2009 to 2016.

No perfect country performance

This year's results highlight that no single country has a perfect record, and that even the top-performing countries still have notable room for improvement. For example, **Switzerland (1st)** received the top ranking overall, but ranked first in only one of the 18 metrics (quality of electricity supply). Similarly, **Norway (2nd)** has nearly the maximum score for energy security, but lags in environmental sustainability and, even more so, in economic growth compared to global top performers on these specific dimensions. EAPI results also point to strengths of countries beyond the expected top performers – for example, **China (94th)** is the leader on diversification of import counterparts. **Albania (17th)** and **Paraguay (21st)** boast fully decarbonized electricity generation (0 gCO_2/kWh), which is reflected in above-average environmental sustainability scores. The map in Figure 3 shows that the top performers among a selection of metrics are not confined to any particular region.

However, the index also highlights that, although top performers do not demonstrate top scores across all dimensions, they do reveal balance across the energy triangle. Switzerland, for example, ranked in the top 20 for all three energy sub-indexes.

Figure 3: EAPI top performers across select metrics



Source: World Economic Forum and Accenture analysis

Economies of the Organisation for Economic Co-operation and Development (OECD): still on top

The top 10 rankings are again dominated by OECD economies, underscoring the effect that economic development has on an energy system's performance. While the countries generally have balanced scores across the EAPI, their performance drivers vary. For example, **Norway (2nd)** benefits from an exceptional energy access and security situation, while **Sweden (3rd)** performs very well because of the environmental sustainability sub-index. **Colombia (8th)** and **Uruguay (10th)** are the only non-OECD countries in the top 10, maintaining high performance across the energy triangle, and showing particular improvement in environmental sustainability. Colombia has an installed electrical capacity of 15 gigawatts (GW), including 10 GW of hydro capacity. A recent study forecasts that the country could reach a six-fold increase from its current hydropower capacity, theoretically up to 56 GW (12).

Major economies outside the top 10

In line with previous editions of the index, the performance of the 12 largest economies by 2014 GDP in the EAPI 2016, accounting for nearly 70% of world gross domestic product (GDP), is still visibly lagging across the EAPI energy triangle, a consequence of the relative scale and complexity of their energy sectors. Out of the 12 nations, only **France (4th)** sits among the top 10 performers on the index. The remaining 11 largest economies and their respective scores on the EAPI are: **United States (48th)**, **China (94th)**, **Japan (50th)**, **Germany (24th)**, **United Kingdom (16th)**, **Brazil (25th)**, **Italy (22nd)**, **India (90th)**, **Russian Federation (52nd)**, **Canada (30th)** and **Australia (53rd)**.

Major resource-rich economies may be held back by their focus on domestic supplies and fuel subsidies which, based on the EAPI, often comes at the expense of performance on environmental sustainability. Ease of access combined with cheap supplies relieves the pressure for countries to change, and the recent climate pledges will take time to generate tangible improvements.

The United States (48th) continues to perform very well on the energy access and security sub-index, supported by the growth of unconventional oil and gas production. Energy imports, expressed as the share of energy use, dropped from 25% in 2008 to 15% in 2013. In parallel, fuel prices at the pump dropped by 27% for gasoline and 39% for diesel. Amid the drop in crude oil prices, fuel subsidies continue to distort fuel prices at the pump. Figures from the International Monetary Fund (IMF) show that fossil-fuel subsidies amount to $2,180 for every American. Although US President Barack Obama backed their phasing-out, federal fossil-fuel subsidies have, in fact, risen (13).

The Russian Federation's rank **(52nd)** reflects the prevalence of domestic oil and gas in its energy sector. While economic growth is supported through export revenues and affordable energy, fuel price distortion has driven the fall in the ranking relative to recent years. Alternative and nuclear energy remained stable at 9% over the last seven years, and the strong predominance of fossil fuels in the energy mix is contributing to poor air quality, according to index data.

Australia (53rd) rose eight places in the overall ranking compared to the 2009 benchmark thanks to strong performance on the economic growth and development sub-index. However, Australia's relatively poor performance on environmental sustainability has heavily penalized its overall score, with the country producing some of the highest CO_2 emissions from electricity production (ranked 120 out of 126 countries), with almost no progress over the last seven years. In fact, Australia took a step backward in 2014 when it became the first developed nation to repeal carbon laws that put a price on greenhouse gas emissions.

In contrast to these resource-rich nations, other major economies depend heavily on energy imports. However, their weak performance on the EAPI due to imports is often balanced by energy policies that promote environmental sustainability, seek to reduce commercial balance deficits and increase efficiency of usage. This group of countries generally performs better than the first group, according to the index.

Following the nuclear accident in Fukushima, Japan, **Germany (24th)** decided to phase out nuclear energy production by 2022, and aims to reduce emissions by 80% by 2050. While the country has built impressive capabilities across the renewables value chain, the energy transition so far has come at a cost: the EAPI highlights sharp increases in electricity prices for industry, and German households, according to data in the index, pay the second-highest prices for electricity in Europe. As a result, the country dropped eight places in the ranking against the 2009 benchmark.

Similarly, **the United Kingdom (16th)** has ambitious policies to reduce its carbon footprint. The country had 12.4 GW of wind capacity at the end of 2014 (14), increasing the shares of alternative and nuclear energy in its mix from 13% in 2009 to 15% in 2013. The sub-indexes related to environmental sustainability and energy access and security both benefitted from this trend. The UK Green Investment Bank, created and owned by the UK government, has been an important force backing green projects on commercial terms and mobilizing other private-sector capital in the country's economy.

Amid slow renewable energy penetration, the performance of **Japan (50th)** continues to be affected by the consequences of the Fukushima nuclear accident and in particular by the high costs of energy imports and increased CO_2 emissions. Japan also demonstrates the challenges that nations can face from sudden supply disruption and the need for greater diversification in the power supply. The country's CO_2 emissions from electricity production have increased by 25% to 562 gCO_2/kWh since 2008, while the share of alternatives and nuclear energy dropped from 17% in 2008 to 5% last year. Despite the introduction of aggressive feed-in tariffs for renewable energy in July 2012 (15), the contribution of renewable energy is still too limited to reverse this trend. Japan's government is now seeking to restart some nuclear reactors to cut the nation's dependence on imported energy.

The largest among the fast-growing economies are pressed by the need to support economic growth and the necessity to build a resilient and sustainable energy architecture over time.

Brazil (25th) is the top performer among the BRIC nations (Brazil, Russia, India and China). It benefits from a diversified energy mix with a considerable share of low-carbon energy, and a growing domestic oil and gas sector providing revenues and reducing the need for energy imports. With its electricity supply dominated by hydropower, Brazil achieves a comparatively high score for environmental sustainability. However, its energy architecture is also deteriorating; shares of alternative and nuclear energy dropped by 6% in seven years, and the country has experienced a 10% increase in CO_2 emissions from electricity generation over the same period. Its score for the quality of electricity supply also decreased in 2014-2015 compared to 2008-2009.

The performance of **China (94th)** has been relatively stable, and is an example of how the scale of energy architecture can induce inertia in an environment of rapid change. The country now imports 12.7% of the energy consumed, compared to 8% in 2009. Overall, some good signals exist, such as the government's efforts to curb pollution levels and the strong progress in providing access to energy. However, its sustainability metrics still lag behind many countries, with the share of non-fossil fuels decreasing by 2% since 2009.

Finally, **India (90th)** is facing a vast array of challenges in the power sector in order to meet its growth targets. Nevertheless, electrification appears to have progressed, with the proportion of the population covered having grown over the past six years by 4 percentage points to 79%.

The need to become more energy-efficient, more diverse and less carbon-intensive is especially acute for major emerging economies, making it critical to progress with government responses to these pressures through energy reform. The following section assesses the countries that have significantly increased their EAPI scores as a consequence of policy decisions.

Examples of strong improvements in EAPI scores

Several countries have experienced great improvements across the EAPI energy triangle over the last seven years, providing interesting insights for other nations along the triangle's pillars.

In **Uruguay (10th overall; +16 places vs. 2009)**, fuel imports as a percentage of GDP (both at current $ prices) have decreased from 9.1% in 2008 to 3.0% in 2014. The country has also significantly increased its use of alternative and nuclear energy, from 34% in 2008 to 47% in 2013, and has made sizeable investments in green power to become the green-power leader in South America, with the country's wind power capacity expected to reach 1,400 MW in 2017 (16).

Mexico (49th, +11) and **Indonesia (51st, + 11)** each achieved significant improvements. One reason for their progress is a reduction in price distortion related to government subsidies, which can shift and change very quickly; Mexico is phasing out its gasoline subsidy incrementally, and Indonesia abolished gasoline subsidies in 2014 (17). The average fuel consumption by cars in Mexico has also decreased by 8% since 2008, while Indonesia saw a 15.7% increase in GDP created per unit of energy used. The latter reflects that, in the longer term, subsidies fail to provide industries with the appropriate signals to switch to efficient models and cleaner forms of energy. Some indications show that, although energy subsidies provide short-term benefits to economies by improving energy access, they also have tangible downsides in costs to the economy.

The costs of maintaining generous subsidy schemes appear to be growing ever higher for countries that rely almost entirely on oil revenues to finance their fiscal budgets. For example, 80% of total revenues in the **UAE (104th, -7)** are related to oil (17).

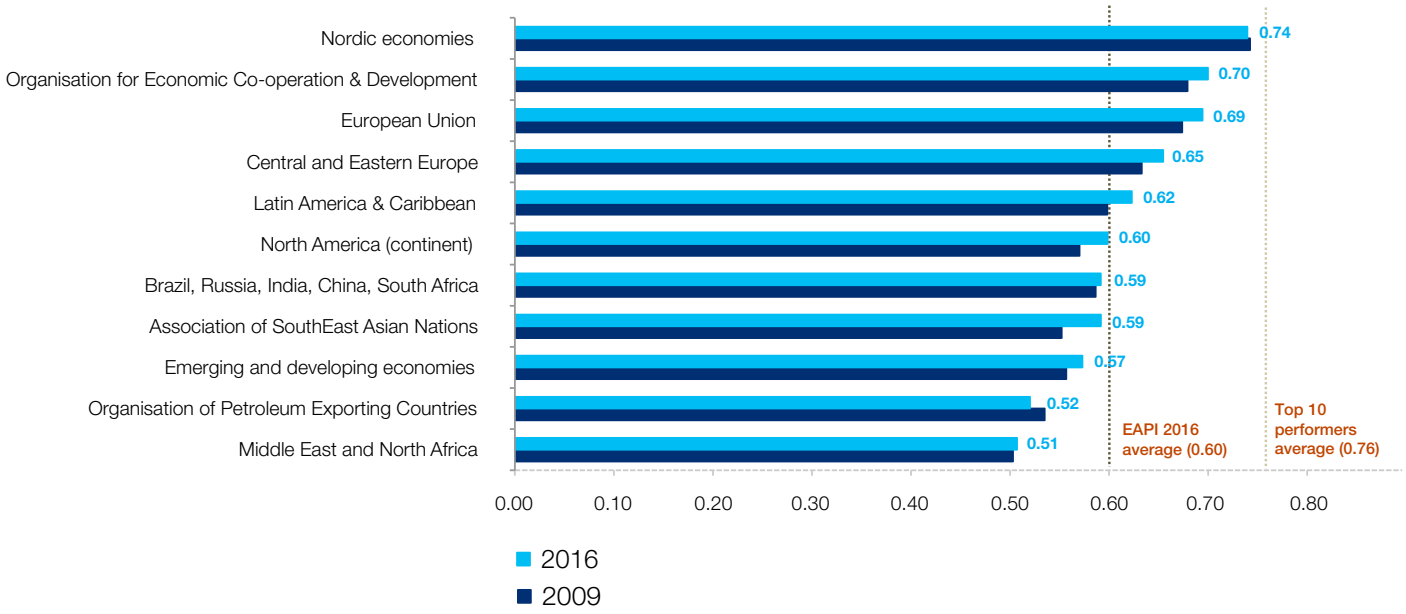
Finally, **Spain (7th, +5)** improved its EAPI score and entered the ranking's top 10. Significant improvement in the environmental sustainability sub-index drove this change, notably through expansion of renewable energy, such as solar and wind. However, given the successful penetration of renewables into the grid, the costs of supporting schemes exploded proportionally, posing significant challenges to the Spanish government. Associated policy adjustments have resulted in the reduction of the tariff deficit to a 10-year low in 2014 (18).

Regional trends

A review of the EAPI over the past seven years indicates that, on the surface, little has changed: the average EAPI score has marginally increased from 0.59 in 2009 to 0.60 in 2016, and the average EAPI scores of certain regions and economic groups (Figure 4) show little variation over time.

A closer inspection, however, indicates that underneath the slow-moving facade is a shifting and interdependent system.

Figure 4: Trends in average EAPI scores by country groups



Source: World Economic Forum and Accenture analysis

For example, while the overall EAPI results of the Organization of the Petroleum Exporting Countries (OPEC) have stayed relatively constant since 2009, **Nigeria (108th, -26)** and **Venezuela (88th, -19)** have experienced steep declines in fuel exports compared to their GDP, which is significantly impacting their economic growth and development. For Nigeria, fuel export ratios to GDP decreased from 36% (benchmark 2009) to 14% (EAPI 2016), and from 28% to 15%, respectively, for Venezuela.

New complexities in energy security

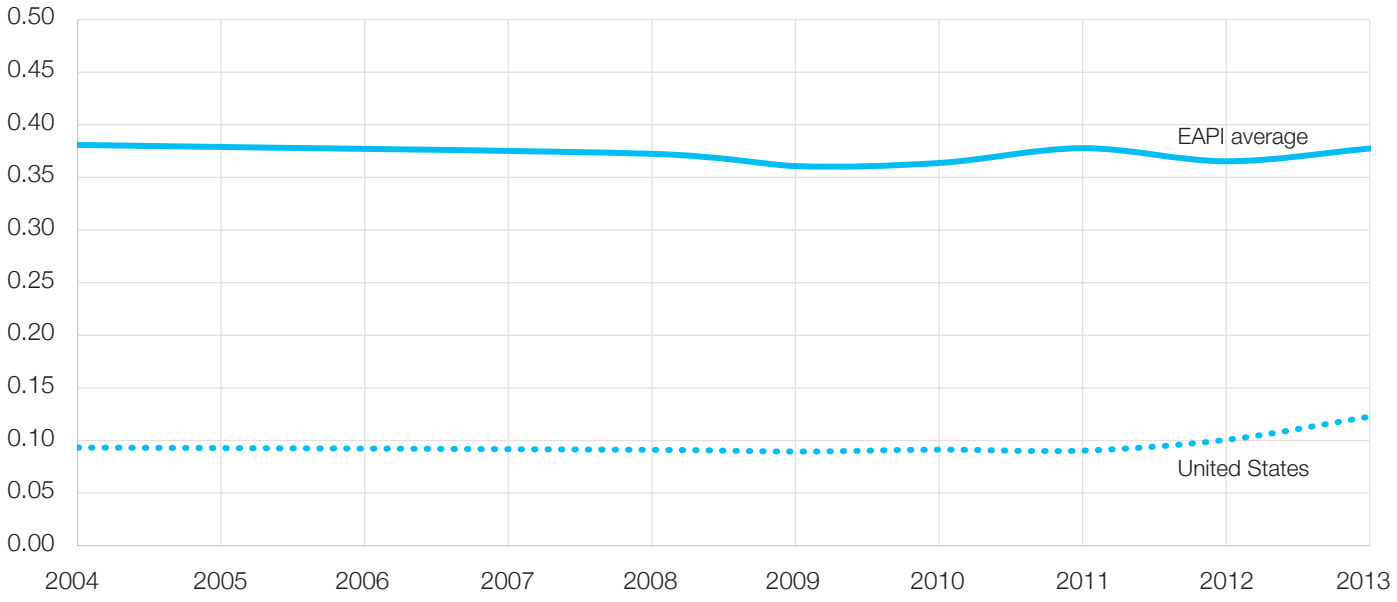
The EAPI shows that the concentration of global energy production in relatively few suppliers has only slightly improved over the last decade, adding to the difficulty of bypassing traditional supply routes and to the stagnation in expanding international trade in energy. However, the supply patterns of certain individual countries have changed; the United States, for example (Figure 5), is experiencing one of the most notable shifts in its trade flows as a result of unconventional oil and gas.

These two asymmetrical evolutions shed light on the complexity of the energy security concept and measures. They also indicate that energy security is closely linked to interpretation and subjective analyses. The EAPI measures both trends with the same weights, resulting in a quasi status quo for the United States. Depending on culture and geographies, some stakeholders would argue that a vast array of suppliers is a sufficient condition for energy security, while others would place control of sources as a top priority in energy security.

The following section takes a closer look at the energy access and security pillar, as well as opportunities and risks

to energy security resulting from new developments in the energy sector. In addition, the implications for governments and companies in ensuring affordable and secure supplies of energy in the short and long term are covered.

Figure 5: Diversification of import counterparts (Normalized Herfindahl-Hirschman Index)
Lower score = higher diversification



Source: World Economic Forum, based on figures from the United Nations Conference on Trade and Development/UNCTADstat

Energy access and security

This section explores the EAPI energy triangle's energy access and security pillar, probably the most complex and unpredictable of the three. Evolution in this area is being shaped by the fast transition underway within the energy sector, with several elements playing important roles, such as the fast growth of distributed renewable energy, the developments in digital technology and international security. Energy access and security within the context of the EAPI framework is covered, as well as an exploration of three critical trends reshaping its landscape:

1. Challenges and opportunities for infrastructure resilience, created by shifts within the energy generation portfolio and the increasing weight of renewable sources
2. New opportunities and threats resulting from the convergence of technologies and physical assets, and the role of technology in connecting demand and supply
3. Shifts in supply routes and low oil prices changing the geopolitical landscape, and therefore affecting energy security

What is energy access and security, and how is it measured?

A common definition for energy security

Energy security is an umbrella term that covers a range of issues linking energy, economic growth and political power, such as the security of energy supply, the level and quality of access and uncertainty over prices (19). The concept emerged in the 1970s as a consequence of supply disruptions and price volatility, which resulted from OPEC oil embargoes in 1973 and the Iranian revolution in 1979. A commonly used taxonomy for energy security, published by the Asia Pacific Energy Research Centre in 2007, is the "four As" of energy security:

– Availability (geological and physical elements)
– Accessibility (geopolitical elements)
– Affordability (economic elements)
– Acceptability (social and environmental elements) (20)

Energy security can be part of a broader vision, where energy is generally an element of global security. The concept has evolved over time and is more frequently viewed in relation to the vulnerability of energy systems. In 2012, the Global Energy Assessment referred to energy security as the "uninterrupted provision of vital energy services" (21). Similarly, in 2014, Cherp and Jewell explored the concept in terms of vulnerabilities and resilience, describing it as "low vulnerability of vital energy systems" (22).

In line with the approach taken by stakeholders such as the International Energy Agency (IEA), an outcome-oriented definition has been adopted here: energy security is "an uninterrupted availability of energy sources at an affordable price" (23).

The framework for understanding energy security

Although the definition of energy security is clear, the dimensions affecting it are more complex. The proposed framework set out here for evaluating energy security includes six components, both quantitative (e.g. self-sufficiency and diversity of supply) and qualitative (e.g. governance and emergency response mechanisms). The quantitative components are assessed by metrics within the index, whereas the qualitative components sit outside the index's scope. Understanding both aspects is critical to providing a comprehensive overview of energy security (Figure 6).

Figure 6: Framework for assessing energy access and security

Framework component	Definition	EAPI metrics
Self-sufficiency and diversity of supply	– No overdependence on one source – No overdependence on one supplier – Reduced dependence on energy imports	– Diversity of total primary energy supply (Herfindahl-Hirschman Index [HHI]) – Diversification of import counterparts (HHI) – Net energy imports (% of energy use)
International security and geopolitical risks	– Overall stability of the geopolitical landscape – Risk of global terrorism and cyberattacks – Risk of war/conflict over energy supply/demand and access to resources and transport routes – Stability of main suppliers	– Not available (qualitative analysis was done)
Infrastructure resilience and flexibility	– Investment in securing and integrating technology infrastructure – Cost-efficient maintenance of existing, ageing infrastructure – Responsiveness to a wider range of vulnerabilities and increased complexity	– Quality of electricity supply – Alternative and nuclear energy (% of total energy use, including biomass)
Economic risks and increases in demand	– Volatility of energy prices – Ability to meet production demand, especially in rapidly growing countries – Recognized interdependence of consumers and suppliers	– Fuel price distortion – GDP produced per unit of energy use – Net energy imports (% of energy use) – Net energy exports (% of energy use)
Level and quality of access	– Minimum level of energy provided to satisfy a nation's specified basic needs – Access to clean, uninterrupted and sustainable sources of energy, compliant with legislation – Access to energy sources that enable economic productivity	– Electrification rate (%) – Quality of electricity supply – Percentage of population using solid fuels
Governance and emergency response mechanisms	– Provisions in place to respond to diverse natural events and possible supply disruptions – Coordinated and well-governed efforts at state, regional or global levels to ensure the right emergency response mechanisms are in place – Proactive engagement and reassurance of the public in the event of an emergency	– Not available (qualitative analysis was done)

The framework encompasses the entire energy value chain, including access to energy resources, production, transportation and consumption of different energy products, such as electricity, natural gas, oil and fuels. It seeks to be universally applicable, as energy security can vary significantly across the value chain and geographies. Therefore, policy-makers and organizations will need to continually evaluate and adapt their energy systems to their current environments. Although some specific areas affecting the EAPI have seen improvement over the years (one notable example is electrification), the overall energy access and security sub-index has not changed significantly in recent years, with its average global value hovering around the same figures.

Energy access and security across geographies

The interpretation of energy security and access varies by country and context, reflecting the relative importance of each dimension given the geopolitical, economic, physical and social environment in a particular region. Self-sufficiency, for example, is an area of concern in regions such as East Asia and Europe, whereas the level and quality of access to energy concern India (24) and Sub-Saharan Africa. A 2014 study by the US Department of State concluded that climate change is one of the most significant long-term security challenges posed by energy considerations (25). Net energy exporters will focus on maintaining "security of demand" (26) in order to keep vital revenue streams. Comparing material

issues globally can be a challenge because they depend on regions. The EAPI framework thus seeks a balance between relevance and objectivity to set an impartial basis for analysis and debate.

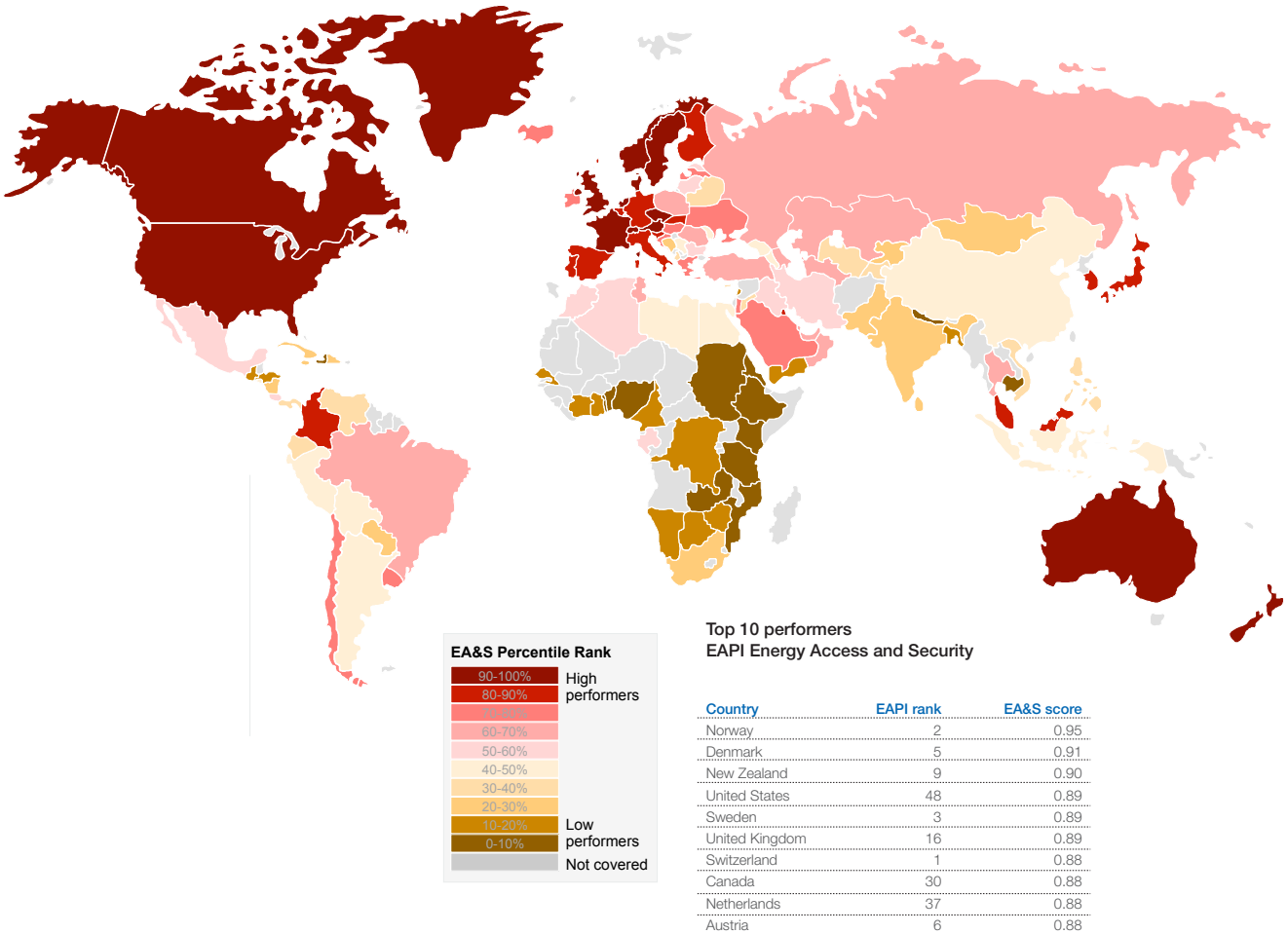
The EAPI shows that self-sufficiency alone does not guarantee energy security. Most countries ranked in the top 10 of the energy access and security sub-index (Figure 7), with the exception of Norway and Canada, are, counterintuitively, net importers of energy. However, domestic production covers a significant share of national demand in these countries, such as in Denmark (although the country's EAPI score significantly benefits from the proximity to the electricity systems of neighbouring Norway and Sweden). Denmark imported 9% of its electricity demand in 2014; while not a significant amount in absolute terms, it was critical for balancing variable input from renewables (27).

The countries with high performance in the sub-index also enjoy a stable geopolitical situation and varied sources of energy supply that leverage both domestic and diversified import partners. A diversified domestic energy mix and a diversified group of energy import counterparts both contribute to a reduced risk of supply disruptions related to any fuel source or energy trading partner. The top performers also have highly efficient energy infrastructures that provide quality access to electricity; these factors more than compensate for their lack of energy independence. In fact, energy imports and trade can support the goal of secure energy supplies at an affordable cost, especially with multiple import and export counterparts. Net energy importers and exporters alike will need to plan and invest in measures intended to improve their overall energy security, even when they benefit from a high degree of self-sufficiency. In contrast, many countries in Sub-Saharan Africa and major developing economies, such as India, score poorly on the EAPI partly due to inefficient energy infrastructures and lack of energy access.

Energy access and security across the supply chain

The dominant concerns for energy security are generally self-sufficiency and access to commodities, but a resilient supply of a range of energy sources across several end-use sectors also plays a crucial role. This demonstrates the close linkage between between supply chains and geographies. For example, about 63% of the world's oil production moves on maritime routes and more than 36% of it across the Strait of Hormuz and Strait of Malacca (28). Serious consequences could arise for the world economy if tensions or conflict threaten these waters.

Figure 7: Heat map representing energy access and security



Top 10 performers
EAPI Energy Access and Security

Country	EAPI rank	EA&S score
Norway	2	0.95
Denmark	5	0.91
New Zealand	9	0.90
United States	48	0.89
Sweden	3	0.89
United Kingdom	16	0.89
Switzerland	1	0.88
Canada	30	0.88
Netherlands	37	0.88
Austria	6	0.88

Source: World Economic Forum and Accenture analysis

Several countries have experienced disruptions in electric supplies in recent years because of heat waves and droughts. In August 2015, for example, Poland's manufacturing output suffered severely after the country was forced to impose limits on electricity consumption owing to low water-levels that had affected the cooling of coal-burning power-stations (29). This issue takes on greater significance when considering concerns about the impact of climate change on water supply and the increasing demand for water to meet other needs, such as irrigation and shale gas production.

Such examples illustrate the critical need for efficient governance and management of the energy supply to address these risks. Inadequate efforts to maintain and improve energy provision across a range of energy sources and end uses can make countries vulnerable to energy supply risks.

How is the concept of energy access and security changing?

With digital enablers and renewable energy, the energy sector has seen more changes in the last decade than in the previous century. Historically, discussions about energy security have centred on securing supplies of hydrocarbons and transporting them to market. Attention has therefore focused on issues such as the stability of the Middle East, the Straits of Hormuz or Europe's relationship with Russia. While these concerns are still relevant, a number of changes to the framework's six components are driving unprecedented change across the energy security landscape. Three key trends are shaping the transition:

Trend 1: Infrastructure and resilience

The transition towards more renewable energy and diversified supplies is creating opportunities and challenges for energy security. Renewables are now part of the energy portfolio and rapidly gaining market share, supporting the diversification of the energy mix and therefore enhancing security. Distributed generation is also growing at a fast pace worldwide, with installed capacity expected to more than double in the next decade (30). Such growth presents long-term potential for improved performance across the value chain. However, as the energy generation portfolio transitions and diversifies further, new challenges are emerging, which require changes to the electric utility business model and regulatory policies to ensure secure and reliable supply (see "Infrastructure resilience during the energy transition").

Trend 2: Digital disruption

The convergence of technologies and physical assets is creating not only new opportunities, but also threats. On the one hand, technology is instrumental for realizing intelligent grids and interconnected assets; on the other hand, it introduces new threats. The increasing interconnectivity and proximity of energy systems mean that conflicts can have ripple effects on energy markets and prices, and the increase of new technologies, such as batteries and grid-embedded generation, is driving an emerging focus on cybersecurity of grid systems. Global inexperience in handling large-scale cyberattacks, combined with the greater capabilities of state and non-state actors, has increased the likelihood that future wars and attacks will have a larger cyber component (see "Digital to accelerate the energy transition" (31).

Trend 3: The new global energy security order

The rebalancing of energy supply and demand is leading to a rebalancing of power and a new global energy security order. The recent drop in oil prices has led to a significant shift in wealth from net oil exporters to oil importers. At the same time, the development of unconventional sources of oil and gas, as well as the recent economic slowdowns in emerging markets, such as China and India, have contributed to price readjustments against the backdrop of a general shift in energy supply patterns. Geopolitical shifts, the new distribution of powers and energy trade flows will create challenges and opportunities for energy security in the new energy architecture (see "The new global energy security order").

Infrastructure resilience, the convergence of technologies and physical assets, and the new global energy security order will affect most regions around the globe and across the energy supply chain. This new energy security paradigm is explored further in the following section.

Infrastructure resilience during the energy transition

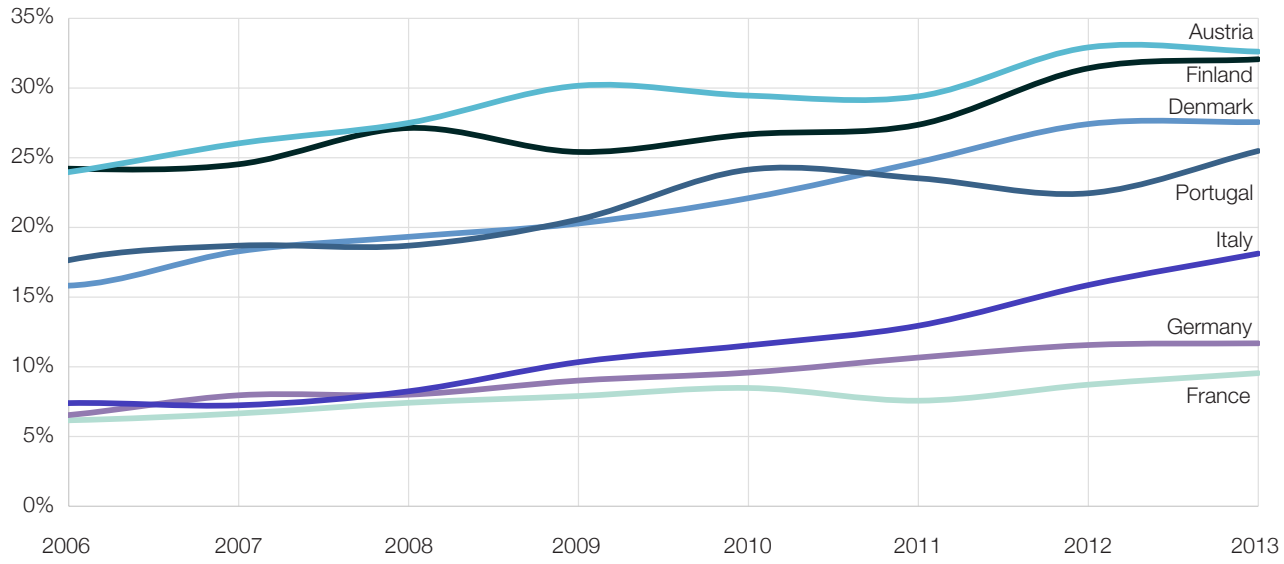
Driven by the need to balance the energy "trilemma" of affordable, sustainable and secure energy, many countries are diversifying from conventional, fossil-fuel-based power generation to systems that favour renewable energy, distributed generation and managed demand. As this trend broadens and gathers pace, it will transform every aspect of how energy is consumed, with long-term potential for improved energy security, lower price volatility and performance across each part of the value chain. However, as countries transition to new sources of supply, new challenges are also emerging, such as intermittency and supply risks. In a decentralized architecture, companies and governments will play a critical role in taking measures that will help reap the benefits of new technologies and ensure supply stability and security.

Increasing diversity of energy supply sources

The primary energy source mix is fundamentally changing as countries expand their portfolios in renewable energy sources. In 2014, global investments in renewable energy rose to $270 billion, a 700% increase within the past decade, and renewables have already become the second-largest source of electricity (after coal) (32). In the same year, renewables contributed 59% of the world's new power generation capacity, and the IEA's World Energy Outlook 2015 expects they will be the leading source of new energy supply through 2040. This increasing diversification of supply is demonstrated by a year-over-year improvement in EAPI scores for diversification of energy supplies.

Despite high growth rates, renewable energy represents only a small fraction of today's global energy consumption. At the country level, however, several nations are leading the transition to alternative energy sources, primarily Austria, Finland, Denmark, Portugal, Germany and France. For example: as shown on Figure 8 below, between 2006 and 2013 Denmark added 12 percentage points to its share of primary energy supply from renewables, in part because of backup capacity made available by the hydroelectric surplus of neighbouring countries. The transition for these nations is even more visible in the electric sector. Globally, renewable electric power capacity skyrocketed by approximately 650% (4) between 2004 and 2014 to reach 560 GW (excluding hydropower), a total estimated to account for 6% of electricity generation (33).

Figure 8: Share of renewables in total primary energy supply (TPES)



Source: World Economic Forum and Accenture analysis

The proliferation of renewables in advanced and emerging economies is also driving gains in efficiency, bringing down costs and creating opportunities for decentralized energy in rural areas. The cost of wind energy has fallen between 60% and 75% over the past 25 years, and solar costs have fallen 50% since 2010 (34). Increasing accessibility of solar photovoltaics (PVs) and power storage equipment is also helping to power rural off-grid areas, bringing hope to the 1.3 billion people without access to electricity (35). Eight of the 20 countries with the largest electrification deficit, in areas such as the Middle East, Asia and West Africa, have succeeded in expanding electrification rates between 2010 and 2012 (36).

Opportunities for infrastructure resilience

Energy supply diversification that includes renewable energy sources and distributed generation is expected to improve performance across the value chain and enhance energy security in the long term.

Diversification of energy supply: Renewable energy has been expanding greatly as the prices of solar PVs and other hardware fall. Investments in renewables also benefit from predictable, long-term incomes as a result of their lower and more stable operating costs, which have a positive effect on commercial balances for importing countries. Overall, the expansion of renewables can contribute positively to diversified energy supply while reducing the costs of and dependence on energy imports. Potential benefits also include energy access where grid infrastructure is unavailable or expansion costs are not justified, an improved supply-demand balance resulting from the combination of distributed generation with smart energy and storage solutions, minimized transmission losses and reduced carbon emissions.

Distributed generation: Technology advancements, cost reductions and government incentives are driving rapid global growth of distributed generation. Currently, countries in the Asia-Pacific, Western Europe and North America dominate the worldwide installed capacity of distributed generation, which is expected to more than double, from 87.3 GW in 2014 to more than 165 GW in 2023 (9). In Germany, for example, the falling price of solar power and battery technology is expected to rapidly make home solar systems cheaper than traditional grid power, and HSBC predicts that power generation from units of 10 MW or less should grow to 50% of the country's power by 2025 (37). Distributed generation can provide opportunities for electric utilities to reduce peak loads, provide ancillary services and improve power quality. It can also decrease the power system's vulnerability to threats and disruptions, and increase the resiliency of other infrastructure (38).

Microgrid resilience: As countries seek to improve the resilience, reliability and efficiency of the electric grid, microgrids offer policy-makers an additional tool for addressing these challenges. According to Navigant Research, the global remote microgrid market will expand from 349 MW of generation capacity in 2011 to more than 1.1 GW by 2017, with most of this growth expected in the developing world (9). Microgrids provide a closer proximity between power generation and use, resulting in efficiency increases and transmission reductions. They can also be integrated with renewable energy sources, such as solar and wind power; this would contribute to security and this contributes to security and independence from grid interruptions, especially for critical facilities such as medical centres, military bases and coastal areas (39). They can provide electricity to critical loads within the microgrid and, at the same time, improve power quality, flexibility and reliability by integrating and optimizing various sources of energy (39).

Challenges for infrastructure resilience

While new energy sources offer opportunities for increased resilience, as countries transition, significant technical and market challenges will arise, creating risks for reliability and security.

Intermittency: Increasing generation from new energy sources introduces new complexities to grid management, and requires effective integration of variable electricity. Because renewable energy sources can magnify sudden shortfalls or excesses in power generation, operators require reserve power or demand-response mechanisms to compensate for the intermittency, and greater flexibility in responding to changes in demand and supply to ensure the grid remains balanced (40). Therefore, dispatchable energy supply and grid flexibility will be critical aspects of grid reliability with an increasing share of renewable energy sources. Nevertheless, experience in recent years, in countries such as Germany and Denmark, has shown that electricity grids can be operated without disruption with a growing share of renewables. Developments in demand-side management, energy storage and data management are also opening up new possibilities that can be leveraged. In addition, and because of geographic diversity and the law of large numbers, renewable energy becomes more predictable as the number of generators connected to the grid increases. Spain and France, for example, benefit from a new interconnected grid line that doubles the electricity exchange between the two countries and has a power capacity of 2 GW (41).

Islanding: Although microgrids can provide many benefits for infrastructure resilience and advance smart-grid infrastructure, they carry the concern of unintentional "islanding", which occurs when a portion of the grid is separated and does not shut down during a power outage. This can cause damaging surges and danger to utility workers who may be unaware that power is still present. Islanding is a barrier to the development of microgrids because it can be expensive to evaluate and prevent, but protocols and new integration technologies can help to reduce the risk (39).

Supply chain risks: As primary sources of energy expand, material complexity and interdependencies create new forms of supply chain risks. Rare earth metals, for example, are important components of renewable solar cells and wind turbines, and are used in emerging technologies, such as electrical energy storage solutions and batteries. Supply-

constrained inputs, such as lithium, cobalt and graphite, risk holding back the growth of these technologies. Supply chains should be designed to ensure the security of market-critical raw materials. As the energy mix changes, it will also create potential risks at the food-water-energy nexus, such as water use in shale gas and bioenergy crop production (42).

Baseload reserve capacity: From a financial perspective, the increased weight of both renewables and distributed generation provides new sources of revenue for energy providers while posing a challenge to the profitability of centralized generations. As already described, renewable generation must be balanced in most cases by conventional power plants acting as backup supply; therefore, existing generators are needed to ensure a secure power supply. This affects cost recovery, because even though generators run less frequently, grid costs remain constant. The Rocky Mountain Institute predicts that by 2030, grid sales erosion in the US Northeast could be as high as 50% for residential consumers and 60% for commercial consumers (42). This heavily affects return on capital employed in centralized generation and has resulted in a number of plant closures. As of January 2014, 10 large European utilities had announced the mothballing or closure of 21.4 GW of combined cycle gas turbine power-plant capacity. These challenges create new questions on how companies, governments and consumers should share the costs and benefits of ensuring grid capacity.

Market transformation and the role of governments

As renewables' share of the energy mix increases, market transformation will be necessary to allow for growth of distributed generation and the profitability of utilities. This will require significant changes to the electric utility business model and regulatory policies. These changes will ensure clear responsibilities for guaranteeing supply stability and security in an increasingly decentralized energy architecture.

Moving away from legacy business models: In addition to fully addressing operational issues, the integration of new energy sources also requires establishing viable business models to incorporate these technologies into capacity planning, grid operations and demand-side management (43). Decentralized supplies challenge the way utilities have long operated by giving customers new levels of control over their energy consumption. The industry's existing one-way value chain – from generation through trading, transport, distribution and retail – is rapidly being transformed in many countries, as distributed generation becomes more prevalent and consumers become "prosumers", who both consume and produce energy. Electric utilities will need to transition to more service-oriented business models focused on grid balancing to support grid-connected consumers with distributed resources, grid cost recovery and new revenue streams to replace centralized energy generation.

Enabling interaction with the demand side: In a departure from the focus on the supply of energy, grid operators and energy companies have recently sought to gain control over the demand side of the equation, allowing consumers – through aggregators offering this capacity service in the market – to serve as virtual electricity suppliers during spikes in demand. In return, consumers have received compensation proportional to the amount of electricity supplied virtually. This space is continuously evolving. France recently changed its policy to put this scheme to public tender, while in the United Kingdom, Electricity North West and Schneider Electric have launched an automated network that is able to monitor and automatically respond to local power demand in real time.

Market mechanisms and regulatory policy will play a critical role in creating pathways for electric utilities to incorporate distributed energy into their business models and to remunerate power-plant operators adequately for providing capacity and ensuring security of supply.

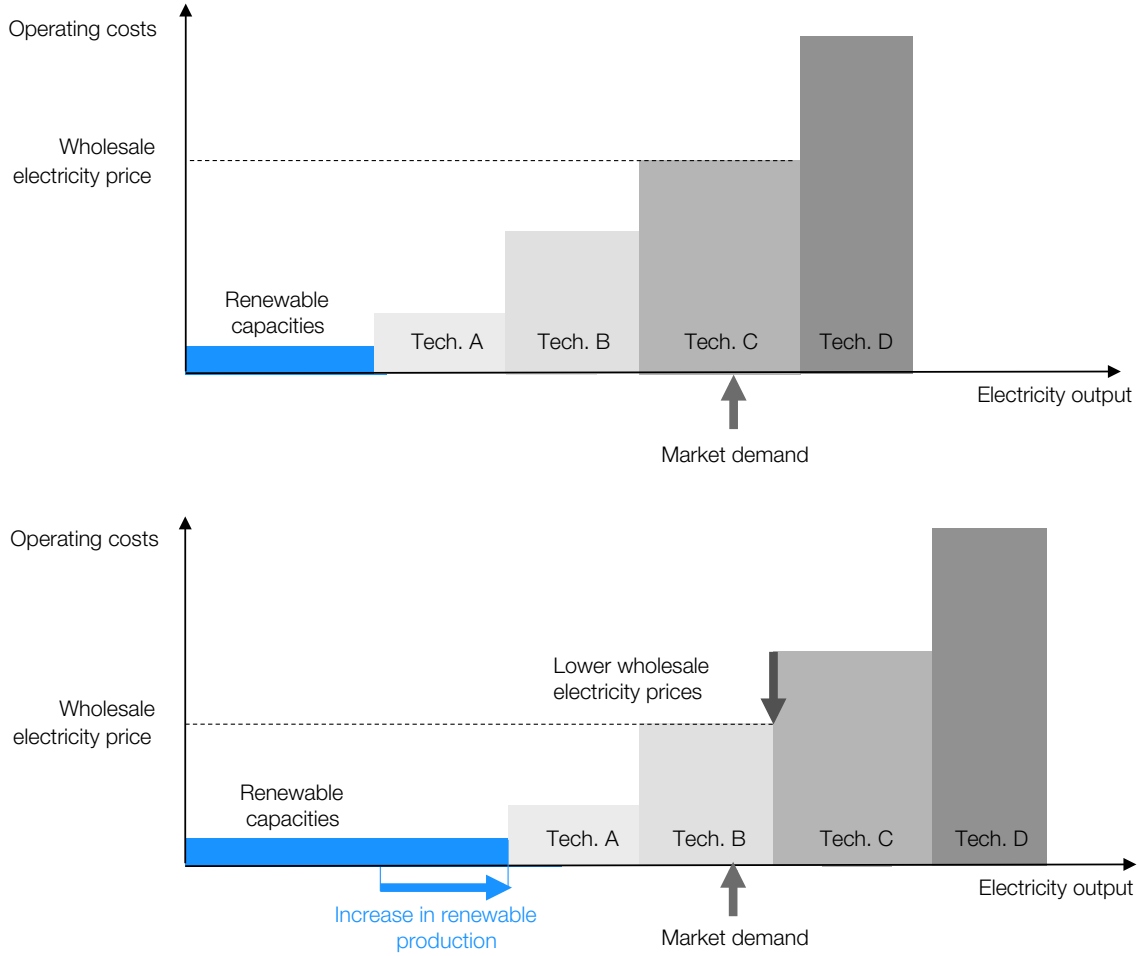
Addressing market distortion: Changing industry dynamics will require innovative legislative frameworks to allow utilities to stay profitable while still enabling innovation and transition. One notable example relates to the influence that renewable energy generation can have on the pricing of energy, which can potentially render traditional, conventional plants unprofitable. Figure 9 shows an illustrative example of this phenomenon: typically, renewable power plants generate low operating costs compared to conventional ones, and when renewable output covers a larger share of the market demand (second graph), conventional power plants could even become unprofitable.

This situation can ultimately lead to periods of negative energy prices if no regulation is in place to prevent them. For example, wind curtailments combined with regional supply-and-demand imbalances in Texas (USA) caused real-time wholesale electricity prices to fall – and even go negative – during periods of substantial wind generation (44). In regions or countries that allow negative energy prices, their occurrence prompts producers to compare their costs of shutting down and restarting power plants with the costs of selling energy at a negative price. If their generation facilities are flexible enough, they halt production until stock prices return to positive figures. Research that favours negative prices shows that the mechanism allows for automatic rebalancing of market distortions and for players who, having benefitted from excessive returns, can feed them back into the system.

In such circumstances, governments must redesign power markets to make them capable of withstanding significant emphasis on renewables, while also ensuring economic viability for backup power plants and demand management solutions as required. Despite recent discussions over the need to allow negative energy prices to be traded on the stock market, such trading is still only allowed in some countries (e.g. those in the European Power Exchange, whereas several other power exchanges do not allow prices to fall below zero).

Figure 9: Power prices in times of low and high input from renewable sources

A, B, C and D represent electricity output and operating costs of conventional energy-generation technologies (illustrative)



Source: World Economic Forum and Accenture analysis

Maroš Šefčovič
Vice President and Commissioner, Energy Union, European Commission, Brussels

Perspective: Policy-makers at the front line of energy security

The EU continues to be dependent on importing energy. It imports about 53% of its energy at a cost of around €400 billion annually, making it the largest energy importer in the world. The EU remains vulnerable to external energy shocks no matter what the roots for this are. A fragile international context, combined with overdependence of some Member States on one particular source or supplier, calls for reinforced efforts to reduce its dependency on particular fuels, energy suppliers and routes.

This is the core message of the Energy Union's strategy adopted by the European Commission in February 2015. Key drivers to achieving a high level of energy security are the completion of the internal energy market and more efficient energy consumption. Moreover, greater transparency, solidarity and trust between the Member States are essential. Diversification of energy sources, suppliers and routes is crucial for ensuring secure and resilient energy supplies to European citizens and companies who expect access to affordable and competitively priced energy. In this context, the work, for instance, on the Southern Gas Corridor, or the establishment of liquid gas hubs in the north, contribute significantly to this objective. The CESEC initiative to provide more diversification via interconnectors to South-East Europe is also a key initiative to this end. Important infrastructure projects can only be carried out in a public-private partnership. Lending from international financial institutions creates additional incentives for leveraging private investments in crucial but also economically viable projects. The EU should also use all of its foreign policy instruments to establish and conduct strategic energy partnerships with increasingly important producing and transit countries.

Both renewables and increasing energy efficiency can contribute significantly to ensuring energy security. The growing share of renewable energy, in line with the EU's 2030 climate and energy framework, requires the modernization and adjustment of the regulatory framework of the electricity market design. The European Commission is intending to come up with such a proposal by the end of 2016. We have to fundamentally rethink energy efficiency and treat it as an energy source in its own right. As part of the market design review, the Commission will ensure that energy efficiency and demand-side response can compete on equal terms with generation capacity. To ensure that the Member States of the EU meet the commonly agreed objectives of the Energy Union, we proposed an ambitious governance structure in November 2015.

Digital to accelerate the energy transition

This section further explores how digital and technology infrastructure can deliver resilience to the energy supply and, specifically, to the electricity sector. Digital disruption refers to the widespread effect that digital technologies have on business, society and the way people think and do business (45). In consumer-focused industries, digital disruption has sparked new entrants and exits from the market, and value transfer within industries (45). While these emergent trends have many benefits, new capabilities are required to manage a vastly more complex and interconnected energy system. Training and investment will be required to ensure protection against an array of challenges ranging from human error to cybersecurity.

Digital and technologies expected to reshape the energy landscape

While big data creates significant opportunity to improve business excellence and mitigate traditional risks, digital technologies are expected to transform the energy sector in a much deeper way.

Big data for operational excellence and risk mitigation

Increasing volumes and velocities of data will lead to significant efficiencies in energy systems. Utilities are rapidly adopting big data, with expectations to spend $37 billion on consumer data tools between now and 2023 (9). Digital data analysis can provide a real-time supply of information and insight on precise end-user usage to eliminate waste from the system (46). Data mining and modelling also provide a more complete picture of risk and vulnerability within energy systems, across supply chains and grids, and down to the level of individual assets. These techniques enhance the decision-making of companies and regulators, helping to set routes and maintenance schedules, understand where to build redundant capacity, and inform hedging and assurance strategies.

Convergence of digital and physical

In parallel, digital and physical infrastructures are converging, led by connected devices, robotics and the Industrial Internet of Things, which will see over 7 billion devices installed across the energy value chain by 2020, creating new levels of insight and control (10). As insights from data become more sophisticated, a combination of machines and information – a digital and physical convergence – is developing new capabilities to act and respond in real time in hugely complex operating environments (47). The energy system's new technical landscape will involve traditional assets alongside sensors, transmitters, robotics and "intelligent" technology, such as smart grids. These technologies are creating an unprecedented ability to collect real-time information from hugely dispersed yet discrete assets across the value chain, enabling far deeper understanding of operational performance and risk.

Technologies set to transform exploration and production (E&P) operations

Analytics companies are providing bespoke data services to help make production more efficient, thereby boosting supply and reducing wastage (46). Artificial intelligence and autonomous vehicles are also increasingly used to monitor both the performance and the security of infrastructure across unsafe or expensive parts of the value chain, such as deep-water assets or assets in conflict zones (48).

Enabling decentralized and connected energy architectures

The greatest advantage of digital technology is its capacity to connect the fabric of energy producers and consumers, allowing for more decentralized and interconnected energy systems (49). Developments in cloud computing, open platforms and mobility are enabling the increasing interconnectivity of businesses, technologies, assets and people (50). These connections are creating new global and local systems within the wider energy value chain (49). The combination of innovations, including connected home platforms and smart devices, is changing energy consumers into "prosumers" and enabling far greater asset efficiency than the "disconnected" distributed generation.

Connected platforms are also offering new ways to address energy system challenges through open innovation (New York New Energy Vision) (51) and crowdsourcing platforms (Kaggle) (52). Dutch start-up Vandebron, for example, uses a "sharing economy" platform for energy services that allows private customers to sell excess supply to other under-users, bypassing centralized utilities altogether (53). RWE, an established utility, is launching a similar platform that also allows resale to the grid. Such platforms create possibilities for super-local energy systems and microgrids, which use centralized supply as backup.

Emergence of new threats to energy security

While digital disruption will bring many benefits for energy security, it will also lead to new risks associated with an increasingly interconnected and technologically sophisticated global energy system (10).

Connected networks: Externality risks

As the digital transformation evolves, attacks on energy infrastructure become a central challenge for governments and companies facing a rapidly evolving and sophisticated threat environment. The energy and utilities sector is among the most vulnerable because of the age of traditional infrastructure, which was never designed for constant security updates, and the scale of potential impact. In 2003, for example, a US blackout caused by a software bug cut energy to 50 million people.[2]

Companies face growing risks of attacks, service disruptions and even infrastructure destruction from hackers, viruses, terrorism and other small- and large-scale threats, with a number of notable incidents. In 2013, Al Qaeda attacked Statoil's natural gas facility in Amenas, Algeria, resulting in 40 deaths including five Statoil employees. A virus attack on Saudi Aramco's network in 2012 disabled 30,000 computers, erased hard drives and replaced critical company data. In 2014, a nuclear plant operator's computer system was hacked in South Korea, and in 2010, a virus damaged centrifuges at Iran's Natanz nuclear fuel enrichment plant. According to the Ponemon Institute's *2014 Global Report on the Cost of Cyber Crime* (sponsored by HP Enterprise Security), average annual losses from cybercrimes in the energy and utilities sector reached $13.2 million (54).

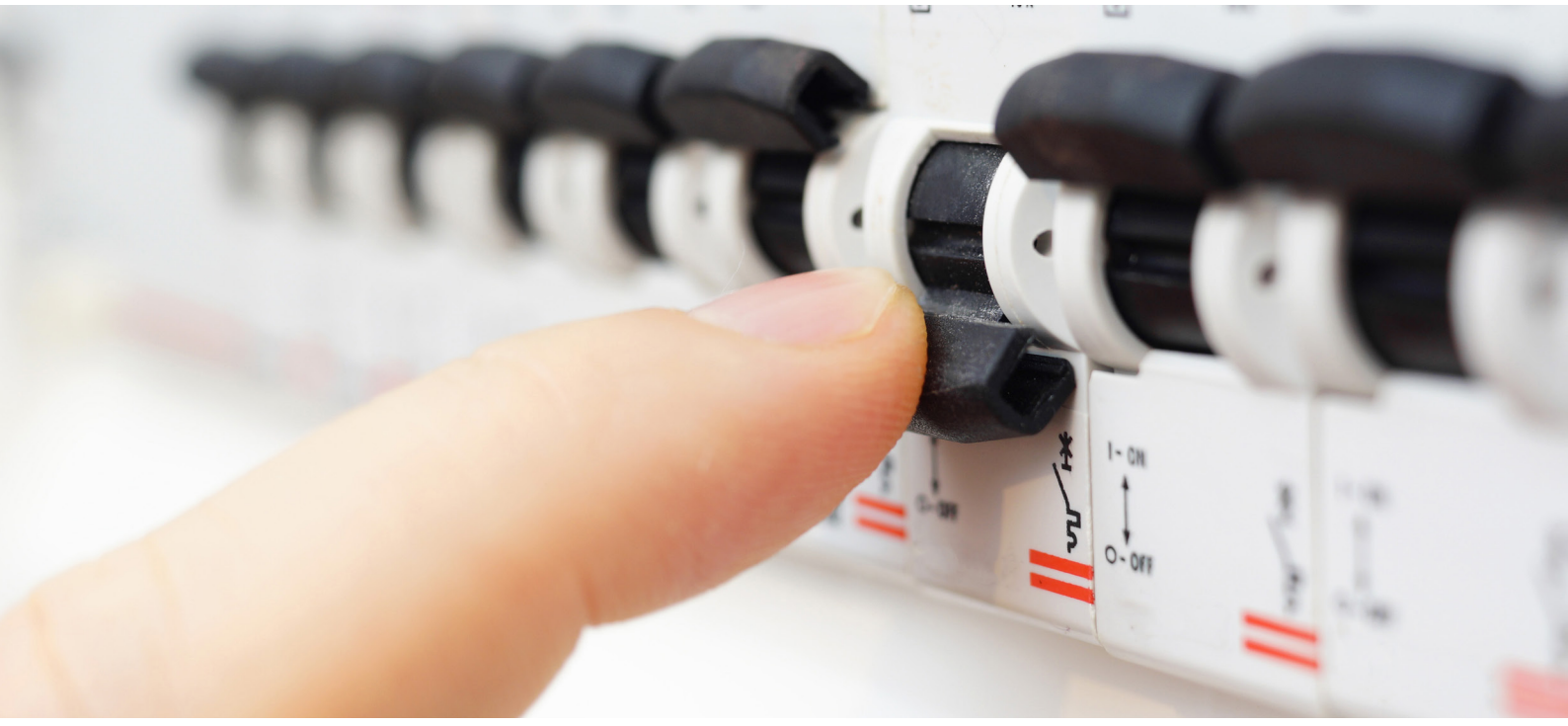
[2] See http://www.scientificamerican.com/article/2003-blackout-five-years-later/

The causes of these attacks range from poor, elementary human practice (phishing, poor password control) to highly sophisticated cognitive programmes that challenge and learn from security controls (55). To increase resilience, energy companies and utilities must take a proactive approach by focusing on prevention, better control processes and greater sensitivity to small abnormalities (56), as tools and methodologies continue to be developed for assessing, evaluating and preventing cyberattacks.

Existing regulatory frameworks are not fit to cope with this evolving context. Regulators will need to drive cross-border collaboration and skills development to address shortfalls in digital capability. In the United States, the government is engaging with utilities and the private sector through a series of initiatives to enhance security of the electric grid and develop cybersecurity standards to better inform investment planning and research and development, and to enhance public-private partnerships (57). Within industry, human resources need to be suitably skilled and the technological infrastructure sufficiently robust and flexible to manage the complexity and interconnectedness of digital energy systems (10).

Shortfall in capabilities

A skills gap is already visible across all levels of the energy system, and this is likely to continue as new entrants, services and technologies introduce further complexity. Despite the emergence of analytic methodologies in upstream oil and gas, only 4% of E&P companies are estimated to have sufficient technological skills and resources to implement an underlying "big data" capability to maximize the impact of data flows (46). A similar skills gap exists among utilities; this shortfall could result in wasted investments, inefficiencies, technological or human error and supply outages, due to failures in managing data or machines.



Perspective: Distributed, digital and demand-side – energy technology implications for energy security

Alex Molinaroli
Chairman, President and Chief Executive Officer, Johnson Controls

In addition to well-known environmental benefits, energy technology innovations are providing new opportunities to address a variety of energy security issues. The International Energy Agency defines energy security as the uninterrupted availability of energy sources at an affordable price.[4] The combination of distributed energy resources, the digitalization of energy infrastructure and advances in demand-side energy management can provide consumers with the benefits of uninterrupted local energy supply in an increasingly cost-efficient manner. The coordinated planning and managing of these distributed assets also has the potential to provide greater energy security at a local, regional and national level.

Recent decreases in solar PV installed costs have driven increased installations at both a utility scale and consumer level. Energy storage technology is demonstrating similar cost reduction trends, with the promise of enabling cost-effective, off-the-grid capabilities to energy consumers. While this emerging trend will be most pronounced in areas like Hawaii, where energy prices are high and feed-in-tariffs are decreasing, consumer and business interest in grid independence is increasing everywhere. Even with relatively low energy costs and a generally reliable energy supply, a recent Johnson Controls Institute for Building Efficiency study[5] showed that 58% of the 687 North American organizations surveyed said they planned to have at least one facility able to operate off the grid within the next 10 years.

Advances in energy-efficient products and demand-side management are also enabling the penetration of distributed generation. It is generally two to three times less expensive to save a kWh of electricity than to generate a kWh. The increased electrification of heating and cooling systems using high efficiency heat pump technology, the application of efficient LED lighting and appliances, and the smart charging of electric vehicles all contribute to greater capacity and lower life-cycle costs for net zero energy buildings and off-grid communities.

The digital transformation of energy systems leveraging smart meters, energy management systems, automated demand response and microgrids also provides energy security benefits. Bi-directional communication between energy producers and consumers, as well as an increasing number of “prosumers” which do both, enable distributed generation and storage to be dispatched to address critical supply shortages and grid stability issues, and to help manage intermittent renewable generation. These combined distributed generation and energy storage capabilities also provide valuable grid regulation and ancillary services to the grid, along with compensation to the distributed energy system owners.

The aggregation and centralized management of distributed energy resources, sometimes referred to as “virtual power plants”, can transform zero energy buildings and community-scale microgrids into regional resources by providing, or freeing up, critical electrical system capacity when needed. In developing economies, leveraging digital infrastructures may allow a “leapfrog” of energy services and technology for communities not currently connected to a national electrical grid. While the benefits of digitalization are numerous, growing concerns over cybersecurity issues remain a critical consideration in energy system design and operations.

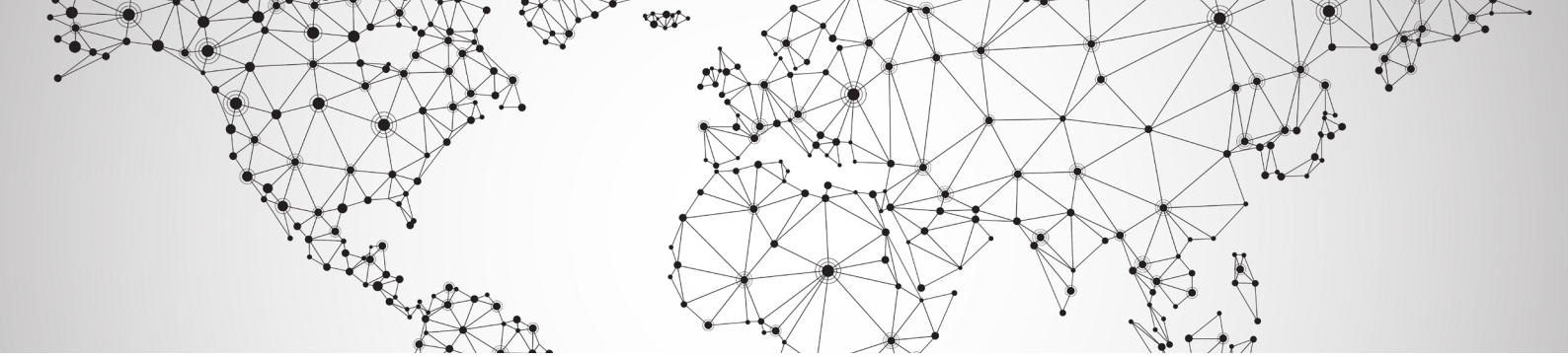
To capture the environmental, economic and resilience benefits of distributed energy resources, the private sector and utilities are evaluating new business models and regulatory strategies to increase adoption while assuring grid reliability and energy security. The New York Reforming the Energy Vision[6] proceeding is an example of an ambitious effort to redefine the role of the utility as a system integrator of distributed energy resources and provider of energy services. The state envisions new third-party business models and revenue streams for utilities to jointly tap the growing market of energy prosumers while maximizing consumer, community and system-wide benefits.

The increases in market adoption of distributed energy resources, digital energy infrastructure and demand-side capabilities are irreversible, driven by emerging customer needs and the increasing cost effectiveness of key enabling technologies. Countries will find it prudent to consider the implications of more distributed and intelligent energy systems within the context of their national energy security and energy systems planning.

[4] See http://www.iea.org/topics/energysecurity/subtopics/whatisenergysecurity/

[5] See http://www.institutebe.com/InstituteBE/media/Library/Resources/Energy%20Efficiency%20Indicator/Energy-Efficiency-Indicator-2014-Summary.pdf

[6] See https://www.ny.gov/programs/reforming-energy-vision-rev



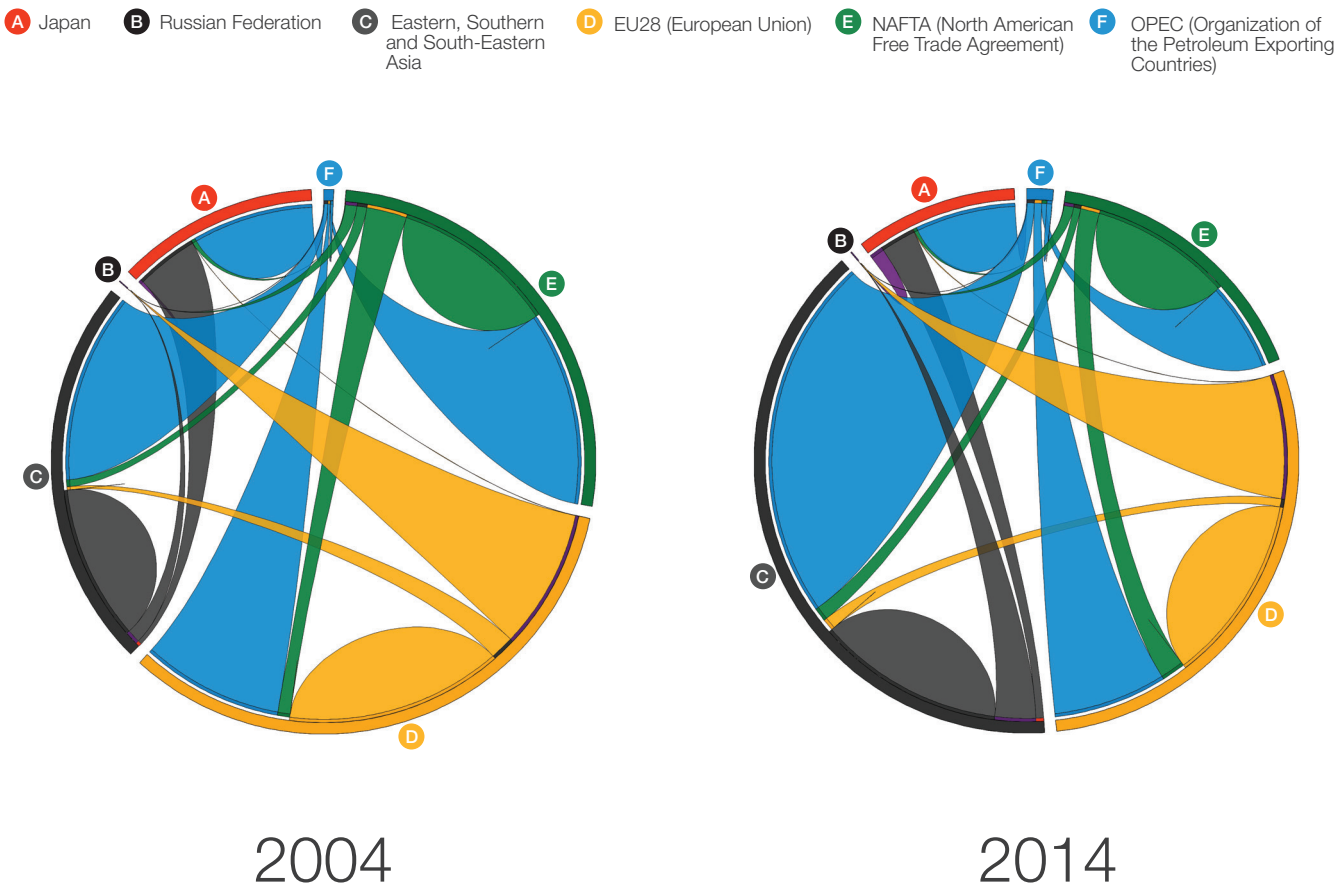
The new global energy security order

Energy is at the crossroads of nearly every dimension of the international security complex. Moreover, a dramatic change in energy supply patterns has occurred over the past decade, with the emergence of giant economies in Asia and unconventional oil production in North America. The resulting rebalancing of energy supply and demand has led to a rebalancing of power around the world, as well as a new global energy security order that will create challenges and opportunities during the transition of energy systems.

Shifts in energy supply patterns

World energy production and imports rose by 3,200 million tonnes of oil equivalent (+20%) over the last decade (58), driven by the boom in the Asian economies and led by China and India. As a result, fuel trade patterns have dramatically changed during this period. In particular, Asia accounted for less than 20% of the world fuel trades in 2004, but this figure has sharply risen to 35% in 2014, leading to a redistribution of forces and new alliances around the world.

Figure 10: Evolution of fuel trade imports by trading partner



Source: World Economic Forum and Accenture, based on figures from the United Nations Conference on Trade and Development/UNCTADstat

The change in energy flows is also largely due to the unconventional oil boom in the United States, which added nearly 8.71 million barrels on the market per day (11), mainly to meet domestic demand, as the 2014 pattern in Figure 10 suggests. As a result, US dependence on Middle Eastern oil is expected to remain low.

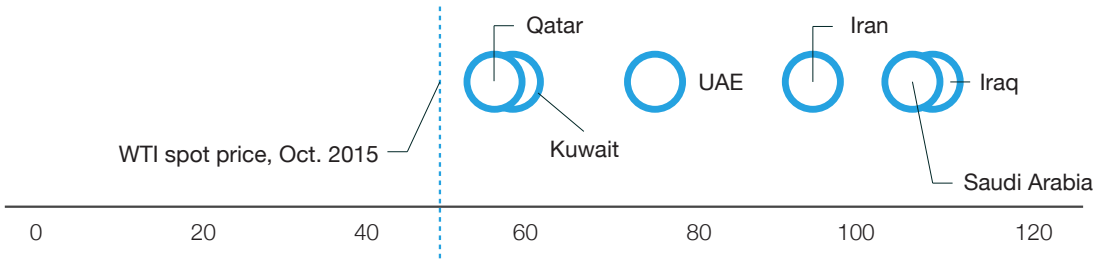
In the future, energy demand is expected to grow. The majority of that demand is likely to come from developing regions, notably Asia, with corresponding impacts on energy trade flows. The IEA's *World Energy Outlook 2015* estimates that by 2040, China's net oil imports will be nearly five times those of the United States, while India's will easily exceed those of the EU. According to the study, corresponding energy trade relationships will follow, with Asia as the final destination for 80% of regionally traded coal, 75% of oil and 60% of natural gas in 2040. The developing capability for trade in liquefied natural gas will also help to better equalize natural gas prices over the next decade between North America, Europe and Asia.

Low oil prices, the new energy norm and possible implications

Taking a short-term view of this new distribution of powers, supply consistently outstripped demand over the past year. The OECD cut global growth forecasts amid "deep concern" over Asian economies, putting China at the centre of the slowdown. In this context of weak demand, with seemingly no one able or willing to be the "central banker of oil", prices remain at low levels. Extracting the benefits from these resources is becoming increasingly competitive and has contributed heavily to the changing geopolitical landscape.

Unconventional US oil production has proven more resilient than OPEC had perhaps expected. In parallel, oil exporters are experiencing significant challenges in balancing their national budgets, facing a potential $1 trillion budget cut over the next five years (59).

Figure 11: 2014 fiscal breakeven oil prices per select countries ($/barrel)



Source: IMF

The outcome of this "endurance race" is difficult to predict, but many countries and companies are experiencing financial strain as a result. Facing a well-supplied market and lower prices, producers have cut operating costs and investment plans. The consequences are already visible in the Middle East. For example, Saudi Arabia has delayed payments to government contractors with the slump in oil prices (60) and the downgrading of public debt by Standard & Poor's in October 2015, resulting in a "pronounced negative swing" in its fiscal balance. This new economic situation, combined with the change of supply patterns, has significant implications for the importance and governance of new geopolitical relationships in the sector.

A new geopolitical order

Key powers that were traditionally able to manage global supply and demand are now under pressure as new powers emerge. Amid low oil prices and financial impacts on oil producers, renewed strategic competition has unfolded between states.

The IEA's *World Energy Outlook 2014* (61) warns that the turmoil in the Middle East will continue to pose a significant risk to oil markets. Assuming greater stability is achievable, the IEA predicts in its new policy scenario that oil production from Iraq and the rest of the Middle East can fulfil most of the expected global increase in demand of 14 million barrels per day until 2040. While the Middle East and North Africa are in dire need of greater economic diversification, inclusion and socio-economic development, the majority of the growth in both regions will continue to come from petroleum. In a tumultuous geopolitical landscape, the key actors in the Middle Eastern energy sector have an opportunity to play a positive role in ensuring greater economic security through diversification and socio-economic development. As the energy sector transforms, energy politics in the region must change from being divisive to enabling sustainable and inclusive economic growth, which will be critical to security in the region and beyond. With increasing energy demand in newly emerged markets, such as China and India, and a shift in the centres of production to the Middle East, Africa and Central Asia, a volatile energy security will endure at the mercy of great power relations. Iran is also emerging as a potential major supplier of oil and gas to international markets in years to come, provided sanctions are lifted.

Russia will continue to play a critical role in securing a fragile geopolitical balance. The country has demonstrated the

volatility of EU dependence on its oil and gas by threatening to increase gas prices drastically and cut supplies to those whom Moscow perceives as allies of the West. In addition, the EU and the US employed economic coercion through sanctions in an attempt to stymie Russia's behaviour. Geopolitical tensions between Russia and the West, together with growing demand for energy in Asia, have contributed to stronger Russian interest in "pivoting to the East", as illustrated by the signing of significant gas delivery contracts with China.

The changing security environment in Europe and the future of the European project will likely dominate more of the energy landscape in coming years. Europe remains reliant on natural gas imports from Russia. European countries get almost 40% of their natural gas (62) and a third of their oil from Russia (62). For the future, EU countries are signalling increased willingness to pursue a common energy platform through the European Energy Union, and their ability to diversify energy sources and imports will be tested. Thus far, the EU has managed to stay fairly united over the crisis in Ukraine, perhaps to the surprise of Moscow, which may have expected sanctions to be short-lived. The refugee crisis, however, seems to present a greater challenge to European unity, and severe disagreements during the integration process could result in fractured relationships and implications for its common front on energy policies.

As illustrated in the three focuses covered in this section, the energy sector has encountered shifting geopolitical challenges. Beyond the classic chess match between nations and trade partners, hybrid threats have multiplied and, as previously outlined, "cyber" has become a new frontier for conflict. More actors – non-state organizations, individual citizens, youth, companies and new coalitions – are becoming relevant and in previously unforeseen ways, which could strengthen or threaten international security arrangements.

New opportunities and increased collaboration

Centralized energy sources (e.g. oil), balance of power and geopolitics are closely linked, while renewables, distributed energy and decentralization of sources could significantly change the landscape of power.

Trends in renewables are significant in some countries, however, they are still mainly limited to generating electricity. For instance, the EU aims to have 10% of the transport fuel of every EU country come from renewable sources, such as biofuels, by 2020. In other words, Europe will still rely on fossil fuels to supply 90% of the energy used by the transport sector. To decrease import dependencies, these regions will need to accelerate the transformation of both the sector and transport: electrification of vehicles, optimization in the use of assets through platforms of the sharing economy, and support in the use of public transport should all significantly improve the sector's efficiency.

If individual countries manage to drive and implement efficient and decarbonized energy architectures, the balance of power in some regions could significantly change. From this perspective, some countries will emerge as new powers. The southern part of Italy, for example, has nearly double the solar radiation of Germany. North Africa, Denmark, Portugal, Costa Rica and South Africa have considerable natural assets and open space that could accommodate wind parks, hydropower and solar power. Greater collaboration between naturally advantaged countries and lacking countries will be required to balance this natural surplus. For new energy endeavours to succeed, greater connectivity between nations and improved cross-border management of the energy sector is needed.

Perspective: Geopolitics, energy and global governance: What does it mean for China?

The most important elements affecting China's energy security strategy are global climate change and domestic ecological deterioration. Conventional concepts and approaches of resource and supply-based security are being expanded and rejustified to fit new realities facing the country. Decision-makers at all levels are now in a critical process of reviewing their strategy towards energy security issues at home and abroad for the 13th "Five Year Plan" period (2016-2020). This is crucial for the country to reach its goal of being a prosperous society by 2020. China is currently struggling to deal with a set of challenges connected to oversupply, sluggish demand plus recent issues connected to the US-facilitated TPP and TTIP, and the new Silk Road strategic initiative.

There are varied opportunities available for wider collaboration on energy security. On top of the global arenas such as the G20, China can also count on a dozen regional cooperation mechanisms such as APEC, ASEAN+3, the Shanghai Cooperation Organization and the China-Japan-Korea Cooperation, together with new institutional forces such as AIIB. Moreover, non-governmental platforms such as the Boao Forum and the CICA Forum, proposed by China in 2015, have been effective in garnering wider attention and dialogues on energy security arrangements for Asia and beyond. However, threats remain to cross-border energy transmission and cross investment in South-East Asia, in the Korean peninsula and in North-East Asia, in addition to the risk of terrorist attacks on existing cooperation in Central Asia.

The existing energy governance systems are now losing effectiveness against global recession and an unchartered world. Reforms, not only driven by emerging economies but also by developed ones, are required through modernizations of IEA, IEF and IEC, as well as through active participation and contribution by emerging institutions. In addition to the UN's sustainable and governance programmes, China is working hard to expand global actions towards energy security collaboration, with the intent to enhance such endeavours to new heights when it hosts the G20 presidency in 2016. The World Economic Forum's Global Agenda Councils are qualified to provide quality advice in this regard. There is no evidence of China wanting to challenge the existing governance system. Instead, the country looks forward to collaborating with all relevant international organizations to assist ongoing modernization programmes under new visionary approaches. It is recommended, therefore, that major players take a lead by establishing a high-ranked joint task force to address these issues, with a joint recommendation to facilitate collaboration on energy security arrangements through both governmental and non-governmental channels.

XiaoJie Xu
Chief Fellow of World Energy, Institute of World Economics and Politics, Chinese Academy of Social Sciences

Conclusion

The *Global Energy Architecture Performance Index Report 2016* highlights similar themes and patterns as in previous years, including the top performance of OECD countries, regional strengths and weaknesses, and complex trade-offs and interdependencies across the energy architecture indexes. However, technology and the international backdrop are changing at a rapid pace, creating new challenges that will require companies and policy-makers to quickly develop new strategies for the world's global energy systems.

While a relatively stable pillar of the EAPI, energy access and security will be the nexus of disruptive trends unfolding in the global energy architecture – from new opportunities and risks to infrastructure resilience created by increasing diversity of supply sources, to the threats and vulnerabilities resulting from the convergence of digital technologies, and to physical assets and the challenges and uncertainties of a rebalancing geopolitical landscape. Early action to mitigate the risks and prepare for changing conditions will be critical to future energy security.

The proliferation of distributed energy has brought more diversity to power supplies and new opportunities for energy security, but it also poses new challenges for electric utilities and grid resilience. Technologies such as industrial-scale storage solutions are expected to further facilitate the integration of variable capacities into the grid. Until then, however, some centralized baseload reserve capacity and data-driven forecasting will be critical to grid reliability. The industry's existing business model is being challenged. As distributed generation becomes more prevalent, utilities will need to adapt. Governments can provide the market mechanisms and regulatory policy to help electric utilities integrate new sources of energy and new market players, and to ensure a secure power supply.

The convergence of the technical and physical worlds, while offering unquestionable advantages, also opens the energy system to new threats and security risks. New approaches to governance for physical and technological estates will be required. As many of today's threats affect legacy rather than modern digital systems, investment in robust cyberdefence will be essential to provide intelligent digital responses to digital threats.

Finally, long-term changes in fuel trade patterns between the US, Asia and the Middle East accompany a change in global power and geopolitics. Key powers that traditionally managed global supply and demand may no longer be able to do so to the same extent. Greater collaboration is still required between states to closely monitor an increasing number of hybrid threats, but more actors – including non-state organizations, individual citizens and new coalitions – are becoming relevant, and in previously unforeseen ways, to strengthen or threaten international security arrangements.

Major driving forces are prompting fundamental transformations across global energy systems. Successful transitions, however, will rely on the ability of companies – as investors, owners and operators of energy infrastructure – to ensure affordable and secure supplies, and to reap the benefits of new technologies. Governments will play a critical role by monitoring opportunities resulting from developments in the energy sector, and by taking new approaches to governance to safeguard energy security in the short and long term. At this pivotal juncture for the energy sector, operators, policy-makers, and national and international entities with the capabilities to tackle new digital and physical security threats must collaborate with each other – the critical step to achieving effective and secure transitions.

Appendices

Addendum on methodology

This section presents the methodology behind the global Energy Architecture Performance Index (EAPI) 2016. A more detailed description of the methodology is available online at: http://wef.ch/eapimethodology. The EAPI is a composite index that measures a global energy systems' performance across three imperatives of the energy "triangle": (i) economic growth and development, (ii) environmental sustainability and (iii) energy access and security.

Methodology overview

The EAPI focuses on tracking specific and output-oriented indicators to measure the energy system performance of a variety of countries. It includes 18 indicators, aggregated into three baskets relating to the three imperatives to both score and rank the performance of each country's energy architecture. The EAPI is split into three sub-indexes. The score attained on each sub-index is averaged to generate an overall score. The three sub-indexes are:

1. **Economic growth and development:** The extent to which energy architecture supports, rather than detracts from, economic growth and development
2. **Environmental sustainability:** The extent to which energy architecture has been constructed to minimize negative environmental externalities
3. **Energy access and security:** The extent to which energy architecture is at risk of an energy security impact, and whether adequate access to energy is provided to all parts of the population

Indicators: Selection criteria and profiles

Where possible, the EAPI team aimed to select indicators against the following criteria:

- **Output data only:** Measuring output-oriented observational data (with a specific, definable relationship to the sub-index in question) or a best-available proxy, rather than estimates
- **Reliability:** Using reliable source data from renowned institutions
- **Reusability:** Data sourced from providers with which the EAPI can work on an annual basis and that can therefore be updated with ease
- **Quality:** Selected data represents the best measure available given constraints; with this in mind, all potential data sets were reviewed by the Expert Panel for quality and verifiability, and those that did not meet these basic quality standards were discarded
- **Completeness:** Data of adequate global and temporal coverage, and consistently treated and checked for periodicity to ensure the EAPI's future sustainability

Where data is missing for a particular year within an indicator, the latest available data point is extrapolated forwards until a more recent result is obtained.

Key adjustments for EAPI 2016

The aim is to keep the methodology consistent with previous years' reports for year-on-year comparison. However, minor adjustments are made to reflect issues such as discontinuation of data and improvements to the model. The key adjustments to this year's report are:

- **PM10 replaced by PM2.5:** The model now includes PM2.5 instead of PM10 as a result of improvement to the methodology, since PM2.5 is a more serious health concern than PM10. Smaller particles[6] can travel more deeply into a person's lungs and cause more harmful effects.
- **Fuel prices distortion:** The distortion formula is now based on a fixed range around the optimal price, thereby excluding outliers that were previously included in the data set. As a consequence, countries that offer highly subsidized fuels or highly taxed fuels are "penalized" more.
- **Change in data source for "Population using solid fuels":** Data is now sourced from the World Bank, the Sustainable Energy for All (SE4ALL) database from the World Health Organization, and the Global Household Energy database (instead of the UN Statistics Division of The Millennium Development Goals Database). However, the differences remain limited (± 5%).
- **Normalization:** Minor adjustments have been made in normalization scores.
- **Extreme values removed:** The electricity price for Italy and N_2O emissions for Finland have been removed following reviews of PX-Web databases of ENEL, the Italian electricity company, and of Statistics Finland.

[6] PM = Particulate matter, or microscopic solid matter resulting from combustion and suspended in the atmosphere

Indicators profile

Figure A.1 details each of the indicators selected, the weight attributed to it within its basket (or sub-index), what it measures and the energy system objective that it contributes to, either positively or negatively.

Figure A.1: EAPI 2016 indicators and weight

Energy system objective	Measure (of)	Indicator name	Indicator weight
Economic growth and development	Intensity	Energy intensity, GDP per unit of energy use (PPP $ per kg of oil equivalent)	0.25
	Supports/detracts from growth	Cost of energy imports (% GDP)	0.125
		Value of energy exports (% GDP)	0.125
	Affordability	Degree of artificial distortion to gasoline pricing (index)	0.125
		Degree of artificial distortion to diesel pricing (index)	0.125
		Electricity prices for industry ($ per kWh)	0.25
Environmental sustainability	Ratio of low-carbon fuel sources in the energy mix	Alternative and nuclear energy (% of total energy use, incl. biomass)	0.2
	Emissions impact	CO_2 emissions from electricity production, total gCO_2/kWh	0.2
		Methane emissions in energy sector (metric tonnes of CO_2 equivalent)/total population	0.1
		Nitrous oxide emissions in energy sector (metric tonnes of CO_2 equivalent)/total population	0.1
		PM2.5, country level (micrograms per cubic metre)	0.2
		Average fuel economy for passenger cars (l/100 km)	0.2
Energy access and security	Level and quality of access	Electrification rate (% of population)	0.2
		Quality of electricity supply (1-7)	0.2
		Percentage of population using solid fuels for cooking (%)	0.2
	Diversity of supply	Diversity of total primary energy supply (Herfindahl index)	0.1 / 0.2 [7]
	Self-sufficiency	Import dependence (energy imports, net % energy use)	0.2
		Diversification of import counterparts (Herfindahl index)	0.1 / 0 [8]

[7] For the indicator on diversity of total primary energy supply, net exporters are given a weight of 0.2 (since they are not scored for the indicator on diversification of import counterparts), whereas net importers are given a weight of 0.1 to form a mini-index for diversity of supply

[8] The indicator on diversification of import counterparts only applies to net importers: for these countries, a weight of 0.1 is used (for net exporters, a weight of 0 is used)

Weights, measures and abbreviations

$	All $ in US$ unless otherwise noted
AIIB	Asian Infrastructure Investment Bank
APEC	Asia-Pacific Economic Cooperation
ASEAN+3	Association of Southeast Asian Nations Plus Three
BRIC	Brazil, Russia Federation, India and China
CESEC	Central East South Europe Gas Connectivity
CH4	Methane
CICA	Conference on Interaction and Confidence-Building Measures in Asia
CO2	Carbon dioxide
EAPI	Energy Architecture Performance Index
EC	European Commission
EIA	US Energy Information Administration
E&P	Exploration and production
EU	European Union
g	Gram
G20	Group of Twenty
GDP	Gross Domestic Product
GIZ	German Federal Enterprise for International Cooperation
GW	Gigawatt
HHI	Herfindahl-Hirschman Index
IEA	International Energy Agency
IEC	International Electrotechnical Commission
IEF	International Energy Forum
IMF	International Monetary Fund
ISIS	Islamic State in Iraq and Syria
kWh	Kilowatt-hour
MW	Megawatt
N2O	Nitrous oxide
OECD	Organisation for Economic Co-operation and Development
OPEC	Organization of the Petroleum Exporting Countries
PM2.5	Particulate matter less than 2.5 micrometres in diameter (also called “fine particles”)
PM10	Particulate matter less than 10 micrometres in diameter
PPP	Purchasing power parity
SE4ALL	Sustainable Energy for All
TPES	Total primary energy supply
TPP	Trans-Pacific Partnership
TTIP	Transatlantic Trade and Investment Partnership
UNCTAD	United Nations Conference on Trade and Development
WTI	West Texas Intermediate

References

1. International Energy Agency (IEA). "World Oil Market Report". The recorded difference between the 2014 and 2015 oil supply is based on a comparison between the oil supply figure for Q4 2014 and the oil supply figures for Q1-Q3 2015. See https://www.iea.org/oilmarketreport/omrpublic/.
2. Adams, Christopher. "Oil groups have shelved $200bn in new projects as low prices bite," *Financial Times*, 26 July 2015.
3. United Nations Framework Convention on Climate Change. *Synthesis report on the aggregate effect of the intended nationally determined contributions*, October 2015.
4. Renewable Energy Policy Network for the 21st Century. *Renewables 2015 Global Status Report*, 2015.
5. Bloomberg New Energy Finance. *2030 Market Outlook*, 2015.
6. Chazan, Guy. "The New Oil Order: in charts", *Financial Times*, 11 August 2015.
7. US Energy Information Administration (EIA). *Syria International Energy Data and Analysis*.
8. Sustainable Energy for All. *Progress Toward Sustainable Energy*, 2015.
9. Navigant Research. May 2015.
10. GE Research. *Powering the Future*, 2015.
11. EIA. "Global Petroleum and Other Liquids", data online, 2014.
12. Unidad de Planeacion Minero Energetica. *Primer Atlas hidroenergético revela gran potencial en Colombia*, October 2015.
13. Carrington, Damian and Davies, Harry. *"US taxpayers subsidising world's biggest fossil fuel companies", The Guardian*, 12 May 2015.
14. The European Wind Energy Association. *Wind in power: 2014 European statistics*, February 2015.
15. IEA. *Feed-in tariff for electricity from renewable energy sources (Japan)*, 2015.
16. Parks, Ken. "Uruguay Spends $2.6 Billion to Become South America Wind Leader", *Bloomberg Business*, 17 June 2015.
17. IEA. *Fossil fuel subsidy reform: recent trends*, 26 May 2015.
18. Moody's. *"Spain's electricity tariff deficit is more sustainable in the medium term, but debt remains"*, 2 June 2015.
19. World Economic Forum, in partnership with Cambridge Energy Associates. *The New Energy Security Paradigm*, 2006.
20. Asia Pacific Energy Research Centre. *A Quest for Energy Security in the 21st Century*, 2007.
21. Johansson, Bengt. "A broadened typology on energy and security", *Energy*, vol. 53, 1 May 2013.
22. Cherp, Aleh and Jewell, Jessica. "The concept of energy security: Beyond the four As", *Energy Policy*, 7 September 2014.
23. IEA. "Energy security", http://www.iea.org/topics/energysecurity/.
24. Pargal, Sheoli and Banerjee, Sudeshna Ghosh. *More Power to India: The Challenge of Electricity Distribution*, World Bank, 2014.
25. US Department of State, International Security Advisory Board. *Energy Geopolitics: Challenges and Opportunities*, July 2014.
26. Yergin, Daniel. *"Ensuring Energy Security"*.
27. Energinet. "Electricity generation", www.energynet.dk, April 2015.
28. EIA, International energy data and analysis. *World Oil Transit Chokepoints*,10 November 2014.
29. Reuters. "Poland's power system faces winter test after summer squeeze", 16 October 2015.
30. Navigant Research. *Global Distributed Generation Deployment Forecast*, 2014.
31. BBC News, "US spy chief James Clapper highlights cyber threats", 27 February 2015, http://www.bbc.co.uk/news/world-us-canada-31654050.
32. UNEP News Centre. *"Renewables Re-energized: Green Energy Investments Worldwide Surge 17% to $270 Billion in 2014"*, 31 March 2015.
33. BP Statistics. Renewables in this review. [Online], 2015.
34. International Renewable Energy Agency. *Renewable Power Generation Costs in 2014*, January 2015.
35. IEA. *World Energy Outlook 2011: Energy for All*, 2011.
36. Sustainable Energy For All, op. cit.
37. HSBC Global Research. *Energy Storage: Power to the People*, 2014.
38. US Department of Energy. *The Potential Benefits of Distributed Generation and the Rate-Related Issues That May Impede Its Expansion*, 2007.
39. PWC. *The Future of Microgrids: Their Promises and Challenges*, 2012.
40. Fares, Robert. "Renewable Energy Intermittency Explained: Challenges, Solutions, and Opportunities", *Scientific American*, March 11, 2015.
41. Tsagas, Ilias."Spain's link to France boosts intermittent power", *pv magazine*, http://www.pv-magazine.com/, 23 February 2015.

42. Rocky Mountain Institute. *The Economics of Load Defection*, 2015.

43. Energy.gov, Office of Electricity Delivery & Energy Reliability. *"Renewable Energy Integration"*.

44. EIA, Today in Energy. "Fewer wind curtailments and negative power prices seen in Texas after major grid expansion", 24 June 2014.

45. Reimer, Kai. *Digital Disruption*. 2013.

46. Gartner. *Hype Cycle for Upstream Oil and Gas Technologies, 2015,* 4 August 2015.

47. Porter, Michael and Heppelmann, James. "How Smart, Connected Products Are Transforming Companies, *Harvard Business Review, October* 2015.

48. Sider, Alison. "Big Oil's New Toy: Robotic Solar Surfboards, Prowling the Ocean", *The Wall Street Journal*, 9 May 2014.

49. Accenture Research. *The New Energy Consumer*, 2014.

50. Accenture Research. *Accenture Technology Vision*, 2015.

51. New York State Public Service Commission. "New York State", http://www.dps.ny.gov/.

52. Kaggle. https://www.kaggle.com/.

53. Vandebron. https://vandebron.nl.

54. Ronke, Luke. "Cyber Threat Has Oil And Gas Majors On Edge", *OilPrice.com*, 7 July 2015.

55. Kaplan, Jerry. Humans Need Not Apply, 2015.

56. Tucker, Patrick. "Hacking Critical Infrastructure: A How-To Guide", *Defense One*, 31 July 2015.

57. The White House, Office of the Press Secretary. "Launch of the Cybersecurity Framework", https://www.whitehouse.gov/the-press-office/2014/02/12/launch-cybersecurity-framework, February 12, 2014.

58. IEA, IEA Statistics, http://www.iea.org/sankey/.

59. Parasie, Nicolas. "Mideast Oil Exporters Face $1 Trillion Budget Pinch, IMF Official Says", *The Wall Street Journal*, 21 October 2015.

60. Martin, Matthew. "Saudi Arabia Said to Delay Contractor Payments as Oil Slumps", *Bloomberg Business*, 19 October 2015.

61. IEA. *World Energy Outlook*, 2014.

62. Pongas, Evangelos; Todorova, Ani; Gambini, Gilberto. *Trade in energy products*, eurostat, http://ec.europa.eu/eurostat/.

WORLD ECONOMIC FORUM

COMMITTED TO IMPROVING THE STATE OF THE WORLD

The World Economic Forum, committed to improving the state of the world, is the International Organization for Public-Private Cooperation.

The Forum engages the foremost political, business and other leaders of society to shape global, regional and industry agendas.

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