EYE ON THE MARKET • ENERGY OUTLOOK 2018

Pascal's Wager

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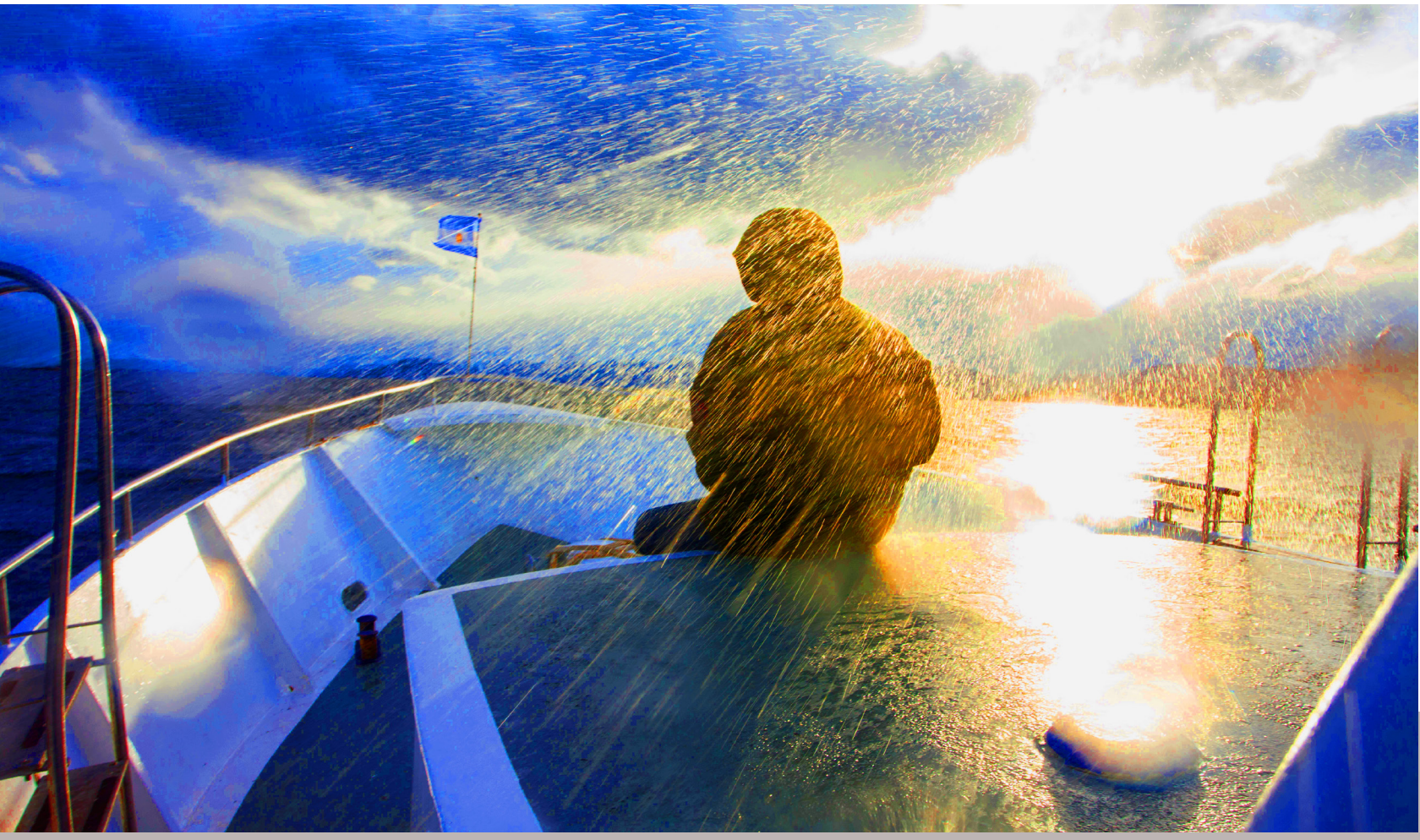


Pascal's Wager argues that belief makes more sense than disbelief when the worst outcome is a total loss. If so, supporting renewable energy makes sense even without knowing the true impact of greenhouse gas emissions on sea levels. However, energy transitions are gradual rather than sudden, defying the expectations of futurists. This year, we examine some timely examples: why climate goals can't be reached by simply decarbonizing electricity with wind and solar power; why natural gas will still be the fuel of the 21st century; the wide range of electric vehicle forecasts after last decade's misfires; the high-voltage transmission bottleneck in the U.S.; and how a group of academics thoroughly dismantled one peer's highly publicized and dreamlike vision of a renewable energy future. As a result, we also look at sea level rise, coastal exposures and flood mitigation infrastructure, which might be needed just in case. We conclude with the intersection between food, energy, urbanization and proposed changes to the U.S. Electoral College.

J.P.Morgan

For the last seven years, we have written an annual **energy paper** that covers 5 topics of interest to us and to many of our clients. Vaclav Smil at the University of Manitoba has served as our technical advisor since its inception, and his insights and guidance have been invaluable to us. This year, our topics include examples of how energy transitions are gradual rather than sudden, defying the expectations of futurists:

- Why climate goals can't be reached by simply decarbonizing electricity with wind and solar power
- Why natural gas will still be the fuel of the 21st century
- The wide range of electric vehicle forecasts after last decade's misfire
- The high voltage transmission bottleneck in the US
- How a dream team of researchers thoroughly dismantled Mark Jacobson's highly publicized vision of a 100% renewable grid

As a result, we also look at sea level rise, coastal exposures and flood mitigation infrastructure, which might be needed just in case. We conclude with the **US Electoral College**, which is under siege again, but best left just the way it is for reasons related to food, energy, urbanization and national security.

Michael Cembalest
JP Morgan Asset Management

Pascal's Wager

Executive Summary

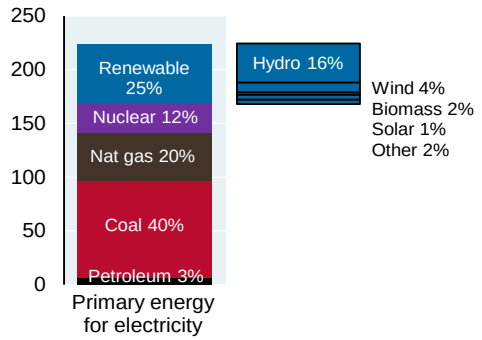
Impressive wind and solar power milestones have been reached in the last few years: ongoing declines in capital costs, power auction prices well below 10 cents per kWh, rising wind capacity factors and rising capacity additions which in 2016 exceeded non-renewable new capacity for the 4th year in a row. These trends, shown in chart form on page 7, are the by-product of scale, innovation and plenty of subsidies.

There's a "but", and it's a fairly big one: electricity **is less than 20%** of global energy consumption. Unless progress is made reducing fossil fuel use by industry and transport, decarbonization goals might not be met in timeframes often cited. If so, outcomes argue for more flood mitigation investment, and a greater appreciation of the critical role that natural gas will play over the next century. Let's take a look.

The first chart shows **primary energy** used to generate electricity, measured in "quads" (quadrillion BTUs). In 2017, the renewable share reached 25%. Hydroelectric power accounted for 16%; wind and solar combined accounted for 5%, up from 0.5% in 2004.

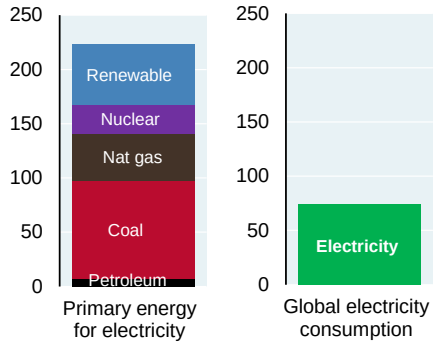
The second chart shows **how electricity gets generated**: 225 quads of primary energy are required to generate 75 quads of electricity. Where did the rest go? 150 quads are lost to thermal conversion[1], power plant consumption and transmission.

Primary energy for electricity: 25% renewable, mostly from hydropower with growing shares from wind...
quadrillion BTU, global



Source: Energy Information Administration, IEA, JPMAM. 2017.

...thermal conversion and transmission losses reduce end-user electricity to 1/3 of its primary energy inputs...
quadrillion BTU, global



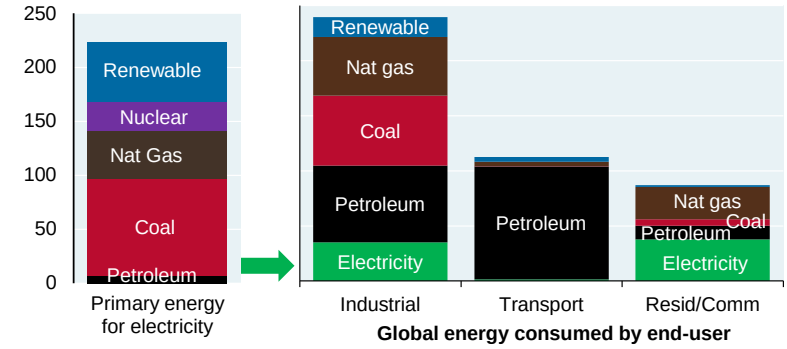
Source: Energy Information Administration, JPMAM. 2017.

[1] **Thermal conversion** losses vary by technology and age. Most US coal plants have thermal efficiency rates of 32%-38%, while natural gas combined cycle power plant efficiency rates are closer to 50%, with record ratings of about 60% for the latest additions. Of the factors mentioned above, thermal conversion is by far the biggest source of energy loss, accounting for 90% of the gap between primary energy and electricity consumed.

While fossil fuels are used to generate electricity, they're also used to power combustion engines, for heating/smelting and as raw materials. In the third chart, we break down global energy consumption into the three major users of energy (industry, transportation and residential/commercial), and their energy sources. **The charts below highlight the limits of decarbonization via electricity alone:**

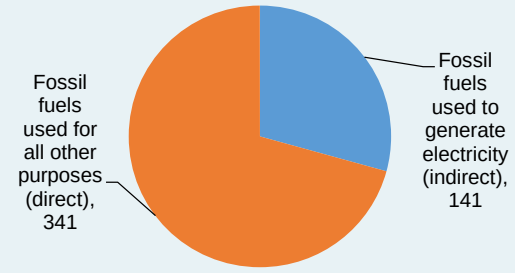
- Electricity is only 17% of global final energy consumption, and is consumed almost entirely by industrial and residential/commercial users (a very small amount is used by electrified rail)
- Electricity accounts for less than one third of global fossil fuel use
- While coal usage still exceeds natural gas, coal displacement by gas is one of the most important emission reduction trends of the 21st century, assuming methane leakage rates below ~3%[2]
- The industrial sector is the largest user of energy and is heavily reliant on direct fossil fuels use (for reasons we discuss on page 5), and transportation is almost 100% reliant on petroleum products

...at which point electricity only represents 17% of total energy consumed, the remainder being direct energy use
quadrillion BTU, global



Source: Energy Information Administration, JPMAM. 2017.

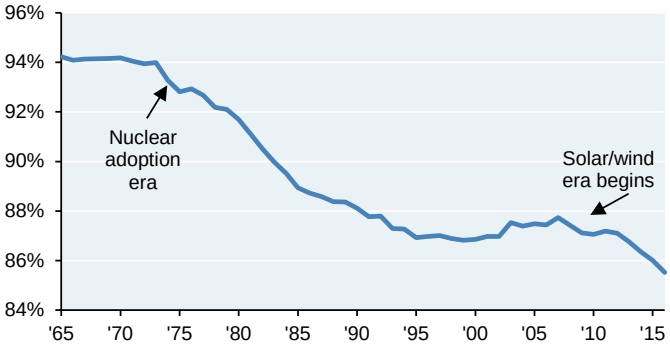
Electricity accounts for less than one third of global fossil fuel consumption
quadrillion BTU, global



Source: EIA, IEA, JPMAM. 2017.

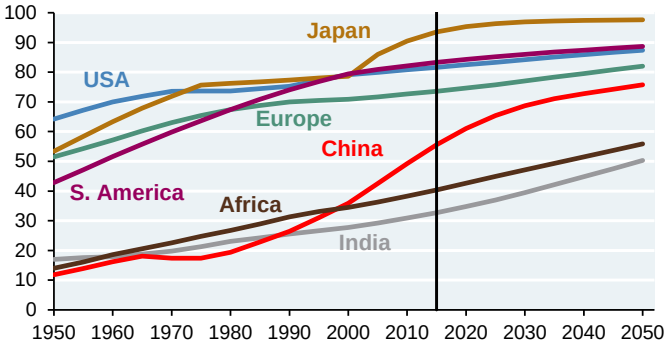
- Fossil fuels accounted for **~85%** of global primary energy consumed[3] in 2016**.** That figure is now gradually declining with the onset of the solar/wind era
- Energy solutions need to be designed for increasingly urbanized societies, rendering discussions about so-called "off-the-grid" approaches even less relevant

The world uses fossil fuels for ~85% of its energy
% of global primary energy consumption from coal, oil and nat gas



Source: BP Statistical Review of World Energy. 2016.

Living for the city: global urbanization trends
% of total population



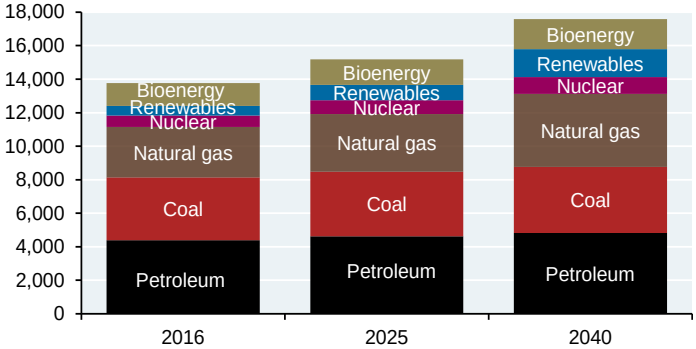
Source: World Bank World Development Indicators. 2015, forecast to 2050.

[2] "*The environmental case for natural gas*", International Energy Agency, November 2017

[3] The BP chart excludes "traditional biomass", which refers to wood, charcoal and straw used for heat. If these energy sources were included as renewable, the fossil fuel figure would drop to ~78%. However, as explained in the note on the bottom of page 4, traditional biomass isn't really "renewable" in the modern sense of the word.

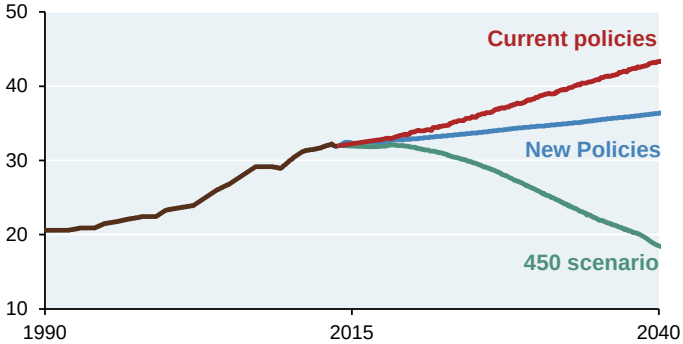
Where does that leave us? Even if renewable sources rose to 50% of electricity generation from 25%, fossil fuels could still represent ~70% of total energy use unless transport and industry decarbonize as well. On transportation, the International Energy Agency has one of the most optimistic electric vehicle forecasts we've seen (see page 10). However, its New Policies Scenario for 2040 **does not show substantial decarbonization of global energy use**. In their scenario, while coal use plateaus and renewable energy doubles, **natural gas meets most of the world's growing energy demand**. Petroleum doesn't decline either, despite the anticipated rise of EVs. When including bioenergy[4], the renewable share expands from 14% in 2016 to just 20% by 2040. While CO_2 emissions grow more slowly in this scenario, they still increase vs current levels.

IEA: Renewables at 20% of primary energy by 2040
Global primary energy use by source, mm tonnes of oil equivalents



Source: International Energy Agency New Policies Scenario. 2017.

Global CO_2 emissions from primary energy demand
Gigatonnes per year



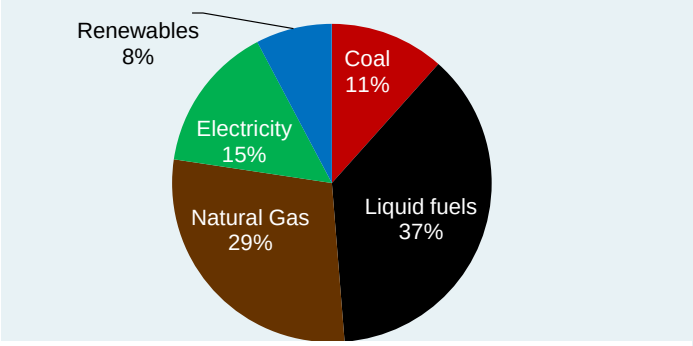
Source: International Energy Agency. 2016.

[4] **The bioenergy question.** Bioenergy currently provides 10% of the world's primary energy. It may sound "**green**", but around 2/3 of bioenergy is consumed in developing countries for cooking and heating, using open fires or cookstoves with considerable negative impact on health (smoke pollution) and environment (deforestation). The remainder represents modern bioenergy used for heat, and smaller amounts used for transportation and electricity. Even modern forms of biomass energy are not as green as you might think, as we covered in last year's paper. **So, most current bioenergy practices are quite different from hydro, wind and solar. Including bioenergy as "renewable" is not straightforward, which is why we break it out.**

The industrial sector and the slow pace of decarbonization

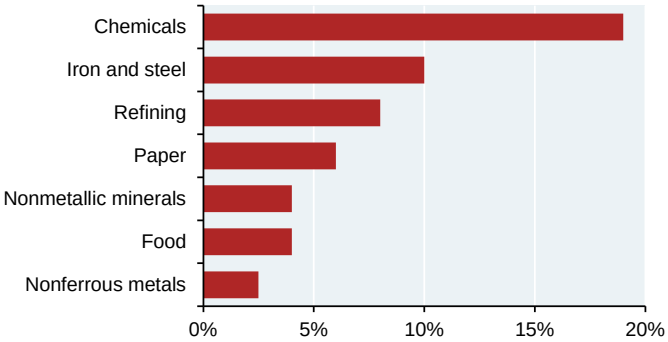
Only 15% of OECD industrial energy use is derived from electricity; the rest is mostly direct consumption of fossil fuels. What does the industrial sector do with all these fossil fuels? The bar chart and tables show examples: oil refining and the manufacture of chemicals, iron, steel, paper and food form the backbone of modern society. These processes are hard to decarbonize as they require two things: **fossil fuels for raw materials, and also for process heat at sustained high temperatures.** While in principle electricity *could* provide some of the latter, there has been only modest progress to-date.

Industrial sector: electricity only 15% of energy use
OECD industrial sector energy consumption by source, percent



Source: Energy Information Administration. 2016.

OECD industrial sector energy consumption by product
% of total



Source: Energy Information Administration. 2016.

Industrial use of fossil fuels as raw materials		
Metallurgical coke	→	Pig (cast) iron smelting (carbon source), which eventually becomes steel
Methane	→	Synthesis of ammonia (hydrogen source), mostly used for fertilizing crops
Methane, naphtha and ethane	→	Synthesis of plastics (sources of monomers)
Heavy petroleum products	→	Production of carbon black (rubber filler), used in tires & other industrial products

Industrial use of fossil fuels to generate process heat
Construction materials (cement, bricks, tiles, glass, kiln-dried timber)
Production of petrochemicals, synthesis of plastics, food and beverage industries
Smelting of iron ores in blast furnaces

That's why **Pascal's Wager** comes to mind. According to the French philosopher, if you believe in God and he does not exist, you experience a "finite loss". But if you do *not* believe in God and he *does* exist, you experience "infinite loss". Consider the following theories:

- Greenhouse gas emissions impact temperatures, which in turn impact sea level rise
- Efforts to substantially decarbonize via wind and solar power will fall short of climate-related goals

Maybe that's right, and maybe it isn't. However, the **infinite** loss case (you don't believe but the theories are true) is much worse than the **finite** loss case (theories are wrong but you prepare anyway). As a result, after looking at electric vehicles and other renewable energy topics this year, we also examine flood mitigation projects in coastal cities, which may be needed just in case. We conclude with thoughts on the intersection between food, energy, urbanization and proposed changes to the US Electoral College: maybe drafters of the US Constitution had more foresight than they're being given credit for.

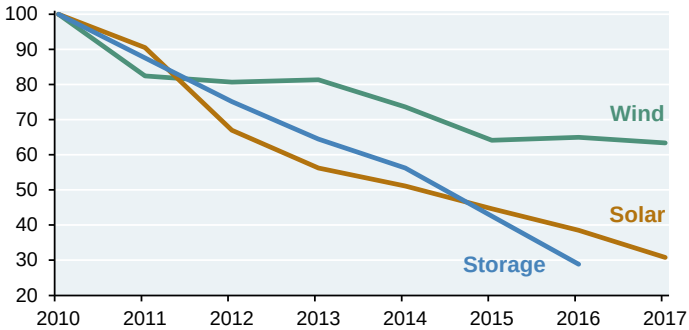
Table of Contents

Executive Summary supplementary materials: renewable energy milestones

The last few years have seen impressive declines in the capital cost of solar power, energy storage and to a lesser extent, wind. The impact of these changes can be seen in several ways:

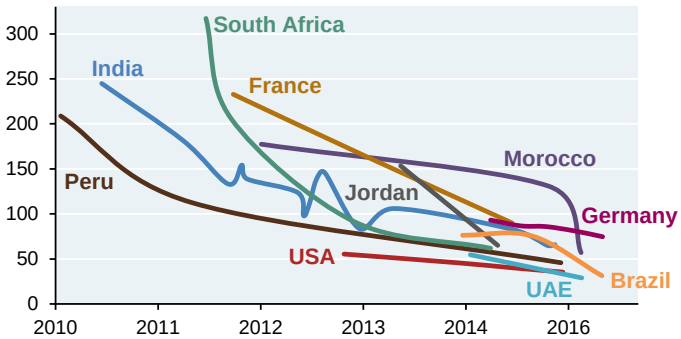
- wind and solar reaching 5% of global electricity generation in 2017 (up from 0.5% in 2004), alongside 16% from hydropower
- wind and solar power auction prices converging below $100 per MWh (10 cents per kWh); the latest US levelized wind power purchase agreements have reached 2 cents per kWh according to the DoE
- continued growth in US and global renewable energy capacity additions, which in 2013-2016 exceeded non-renewable capacity additions
- increases in US wind capacity factors by vintage year, which reflect larger rotor diameters, higher hub heights and locations with better wind speeds

Declining upfront capital costs of wind, solar & storage
Index of upfront capital costs , 2010 estimates = 100



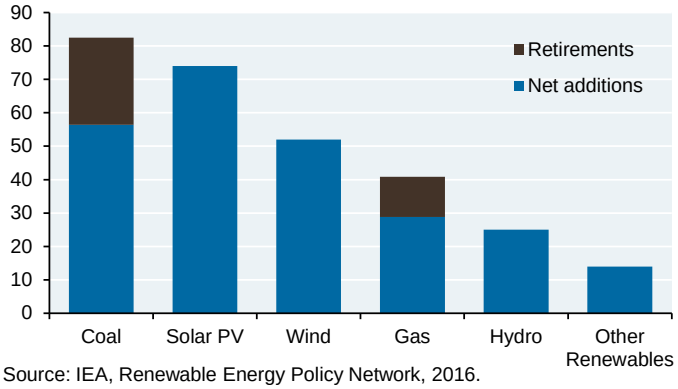
Source: EIA, NREL, Lazard, UBS, Nykvist, et. al. December 2017. Storage proxied by electric vehicle battery packs.

Global solar auction prices converging below $100/MWh
US$/MWh



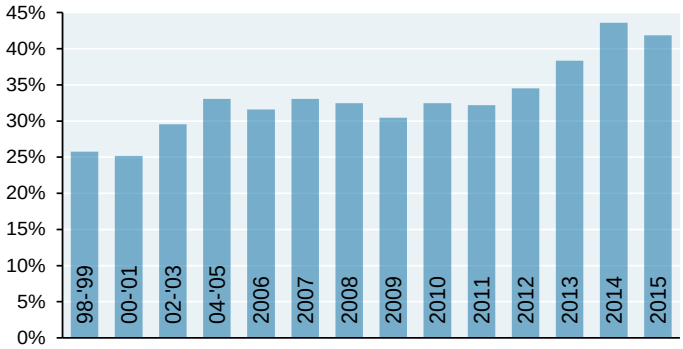
Source: International Renewable Energy Agency. 2017.

2016 Global electricity capacity additions by fuel
Gigawatts



Source: IEA, Renewable Energy Policy Network, 2016.

US wind capacity factors by project vintage year
%



Source: Department of Energy, Berkeley National Laboratory. 2016.

Why all the focus on decarbonization?

I asked Vaclav to articulate for our clients why decarbonization is an important initiative. His response is useful context for both those who are convinced by consensus views on climate science, and also for those who are still on the fence:

> "Underlying all of the recent moves toward renewable energy is the conviction that such a transition should be accelerated in order to avoid some of the worst consequences of rapid anthropogenic global warming. Combustion of fossil fuels is the single largest contributor to man-made emissions of CO_2 which, in turn, is the most important greenhouse gas released by human activities. While our computer models are not good enough to offer reliable predictions of many possible environmental, health, economic and political effects of global warming by 2050 (and even less so by 2100), we know that energy transitions are inherently protracted affairs and hence, acting as risk minimizers, we should proceed with the decarbonization of our overwhelmingly carbon-based electricity supply – but we must also appraise the real costs of this shift. This report is a small contribution toward that goal."

Acknowledgements: our technical advisor Vaclav Smil

As always, our energy *Eye on the Market* was overseen by **Vaclav Smil**, Distinguished Professor Emeritus in the Faculty of Environment at the University of Manitoba and a Fellow of the Royal Society of Canada. His inter-disciplinary research includes studies of energy systems (resources, conversions, and impacts), environmental change (particularly global biogeochemical cycles), and the history of technical advances and interactions among energy, environment, food, economy, and population. He is the author of 40 books (the latest ones, *Energy Transitions* and *Energy and Civilization* were published last year) and more than 400 papers on these subjects and has lectured widely in North America, Europe, and Asia. In 2010, *Foreign Policy* magazine listed him among the 100 most influential global thinkers. In 2015, he received the OPEC award for research, and is described by Bill Gates as his favorite author.

Select topics from prior *Eye on the Market* energy editions (hyperlinks)

- Cost/emissions tradeoffs of high-renewable grids (2017)
- Hydraulic fracturing (2017)
- Forest biomass (2017)
- College campus energy use (2017)
- Distributed solar power and billing changes (2016)
- US hydropower capacity (2016)
- Nuclear power (2014 and 2015)

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