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EXECUTIVE SUMMARY

The dramatic fall in oil prices since mid-2014 has raised questions about whether the availability of cheap crude could derail the movement toward carbon-free energy sources, which has been gathering momentum in the last decade and is essential to the stabilization of the world's climate.

Oil prices can affect the development of alternative sources of energy in a few ways. In transportation, lower oil prices can reduce the competitiveness of biofuels, which have made inroads against traditional fuels such as gasoline in recent years. Cheaper gasoline prices can also reduce consumer incentives to purchase electric vehicles, which are currently more expensive to buy but less expensive to run than vehicles with internal combustion engines.

In the power market, the major way in which lower oil prices could generate competition for renewables such as solar and wind would be through causing a drop in natural gas prices if rigs were redeployed from oil to gas. It is also conceivable, but highly unlikely, that low oil prices could lead to greater use of oil to generate electricity, displacing renewable alternatives and thus increasing emissions from fossil fuels.

This paper explores the way in which oil competes with renewables fuels, and examines the impact a lower oil price environment may have on these fuels. In short, it finds:

- Low oil prices could in principle affect the progress of renewable energy in several ways, by competing with biofuels to displace gasoline in transportation, by making vehicles powered by internal combustion engines more competitive with electric vehicles, and by potentially lowering natural gas prices. Low oil prices have already reduced the appeal of biofuels and of electric vehicles. Biofuels and electric vehicles can still be less costly than their traditional competitors, but the margin is now very fine.

- Because of the regulatory framework in the United States, corn ethanol can compete with gasoline at current oil prices, although there is a growing consensus that corn ethanol has few if any greenhouse gas advantages. For cellulosic ethanol, which is more desirable because it does not compete with food production to the same degree and does not increase demand for land and pressure to clear land, it seems likely that at current gasoline prices in the United States, it is not competitive without subsidies. A critical question is the speed of the development of second-generation biofuels, and whether their production can be scaled up economically.

- In the United States, low gasoline prices make it hard to justify the use of electric vehicles on economic grounds. However, the fact that in the United States most gasoline-powered vehicles return very low gas mileage boosts the competitiveness of EVs. In Europe, EVs should remain competitive with internal combustion engines getting up to 30 miles per gallon with fuel prices of about $6 per gallon and an annual mileage of 15,000. Cost is of course not the only factor affecting the adoption of electric vehicles. Range, charge time, and availability of charging stations are all major issues, so cost parity is no guarantee of market penetration.

- Because little oil is used to generate electricity, the primary impact oil prices will have on the competitiveness of different electricity fuels is through its impact on natural gas, which is used to generate 27 percent of electricity in the United States and around 22 percent globally. The impact of low oil prices on natural gas prices cuts in both directions. In some regions of the world where gas is now very expensive, there will be a drop in gas prices because of the way contracts are written (although there is a general expectation that this aspect of contracts could change). In other regions, the supply of associated gas may fall, and prices may rise, as oil production is cut back. But in yet other regions, resources may be redirected from fracking for oil to fracking for gas, leading to an increase in supply and a drop in prices.

- While oil is used in only a small fraction of power generation in the United States and globally, a comparison of costs shows that even at current lower levels, oil will not compete with renewable energy sources in the generation of electric power. For oil-fired power stations to be competitive, oil prices would have to fall to unsustainably low levels—around $15 per barrel, a price level at which the majority of oil producers would be losing money.

INTRODUCTION

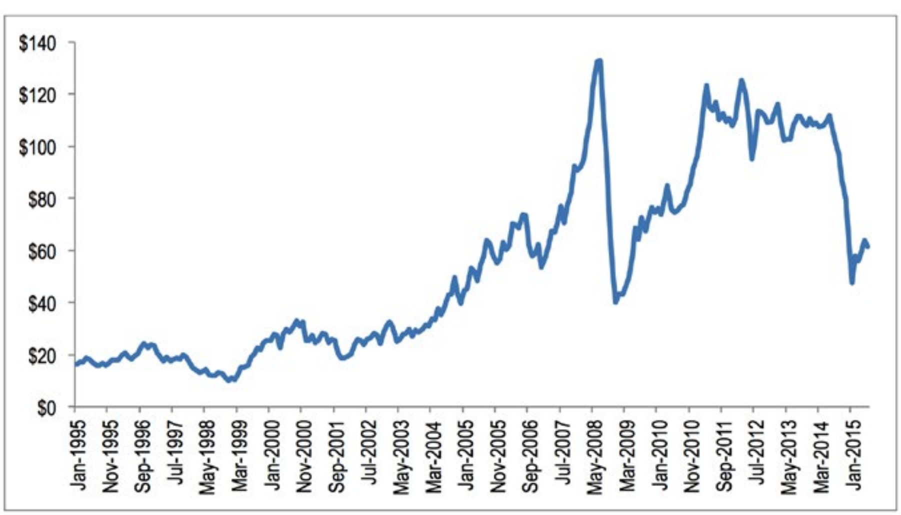
The dramatic fall in oil prices over the past year has raised questions about whether the availability of cheap crude could derail the movement toward carbon-free energy sources, which has been gathering momentum in the last decade and is essential to the stabilization of the world's climate. Such concerns are only likely to grow amid signs that the global oversupply of oil that hit prices in mid-2014 has lasted longer than many had initially expected, and a consensus is emerging that lower oil prices may be sustained over the medium term.

There are two main ways in which oil prices can affect the development of alternative sources of energy. In transportation, prices in the $40–60 per barrel range–where oil has been trading for most of 2015 (Figure 1)–can reduce the competitiveness of biofuels, which have made inroads against traditional fuels such as gasoline in recent years. Cheaper gasoline prices can also reduce consumer incentives to purchase electric vehicles, which are currently more expensive to buy but less expensive to run than vehicles with internal combustion engines.

In the power market, the major way in which lower oil prices could generate competition for renewables such as solar and wind would be by causing a drop in natural gas prices. This could happen if rigs now used in oil extraction in the United States were redeployed to natural gas, which is much more cost competitive with renewables. It is not yet clear, however, what impact lower oil prices will have on natural gas prices. Lower US oil production would be accompanied by a decline in production of natural gas produced from oil wells (associated gas), which would tend to push up prices. However, a wider analysis of whether the redeployment of rigs from oil toward natural gas and a steep drop in services costs and drilling productivity gains would make up for these losses is beyond the scope of this paper.

It is conceivable that low oil prices could lead to greater use of oil to generate electricity, displacing renewable alternatives such as wind and solar power and thus increasing emissions from fossil fuels. Careful analysis indicates that would be highly unlikely. We use data for the United States, which currently only generates about 1 percent of its power through burning petroleum (globally, about 5 percent of power is generated from oil, according to the IEA), but the arguments apply to any country where oil prices are no lower than in the United States and renewables no more expensive. This certainly includes China and the European Union. We show below that even at the lower end of the $40–50 per barrel oil price range, electricity from oil will cost well over $0.10 per kilowatt-hour, as opposed to $0.04–0.07 for power from wind, and about $0.08–0.10 for utility-scale solar PV. And this is before we make any allowance for capital or labor costs.

Figure 1: Monthly Brent crude oil prices, January 1995-June 2015
(In dollars per barrel)



Source: Authors' calculations.

THE NUMBERS IN DETAIL: OIL AND TRANSPORTATION

Oil's highest-value use is as a transportation fuel, and in this role it has few rivals. Emerging and potentially carbon-neutral rivals are bioethanol and biodiesel. Ethanol can be added to gasoline as a partial replacement, and biodiesel is a substitute for conventional diesel fuel. In the United States, the Renewable Fuels Standard requires a minimum volume of renewable fuel be blended into the overall transportation fuel mix. Ethanol can be produced either by fermentation of foodstuffs such as corn or sugar, or from nonfood cellulosic materials, the hard, woody parts of plants that humans cannot digest. Currently the great majority of ethanol used in transportation comes from fermentation of foodstuffs, either corn or sugar, meaning that the production of fuel competes with that of food for scarce agricultural land. Cellulosic ethanol is preferable for this reason, and is also preferable from a greenhouse gas emission perspective: it can be produced from the by-products of food plants. A gallon of ethanol contains only about 70 percent of the energy in a gallon of gasoline, so in cost comparisons, ethanol prices must be increased by about one-third to make them comparable with gasoline. Biodiesel is currently also produced from food crops, although in the medium term there is some prospect of its coming from algae-based production processes.

Because ethanol is produced from foodstuffs by chemical processes involving heat, its cost depends on the costs of the foodstuffs and of natural gas, used for process heating. All of these are volatile, leading to fluctuations in the cost of ethanol production. Figure 2 shows ethanol break-even costs for production from corn in the United States for the last seven years: the price needed for breakeven has varied from a low of $1.10 per gallon to a high of $2.50.

Figure 2: Ethanol break-even price
(In dollars per gallon)

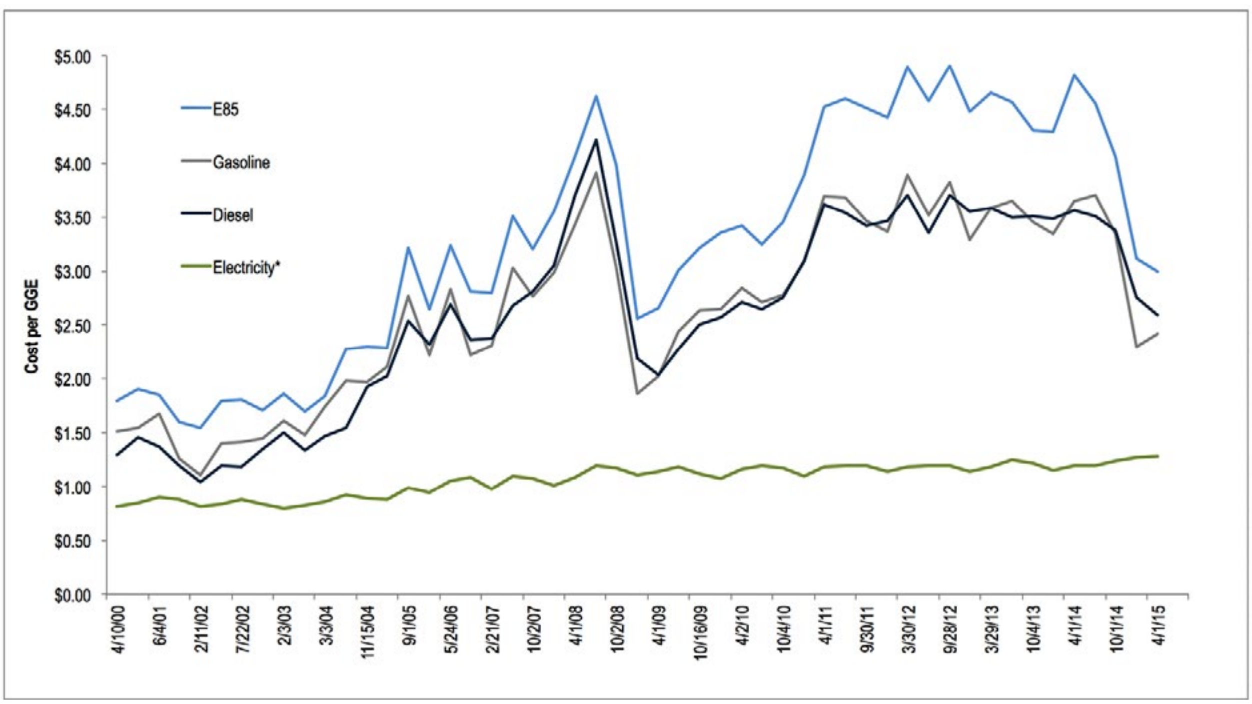
Source: Don Hofstrand, Iowa State University—2015.
Extension and Outreach, "Ag Decision Maker, D1–10 Ethanol Profitability."

Figure 3 shows recent retail gasoline prices and retail E85 prices on a per gallon of gasoline–equivalent basis. For several years the price of E85 has exceeded that of gasoline after adjustment for energy content. But the Renewable Fuels Standard requires ethanol blenders to use a minimum amount of ethanol, and blenders can also benefit from the sale of RIN numbers, the prices of which have spiked to close to a dollar per gallon of ethanol at times this year, and these offset any loss from the sale of ethanol.

Cellulosic ethanol avoids competition with food and provides more environmental benefits than corn or sugar ethanol, but it is more costly than those fuels. It is not currently produced in bulk, although a small number of large-scale production plants are now operating and more will enter the market within the next two years. A recent review in Bloomberg New Energy Finance suggests that cellulosic ethanol currently costs $3.50 per gallon, but that it is expected to fall in cost to be competitive with corn-based ethanol by 2016. The National Renewable Energy Lab also suggests that the cost could fall to about $2.15 a gallon by 2016.

The bottom line here is that because of the regulatory framework in the United States, corn ethanol can compete with gasoline at current (August 2015) oil prices, although there is a growing consensus that corn ethanol has few if any greenhouse gas advantages. Cellulosic ethanol, which is more desirable because it does not compete with food production to the same degree and does not increase demand for land and pressure to clear land, is so new that it is not clear what its costs are; however, it seems likely that at current gasoline prices in the United States, it is not competitive without subsidies. Whatever the break-even costs of ethanol versus gasoline are, given the current infrastructure constraints there is limited ability for the volume of ethanol to go above 10 percent.

Figure 3: US retail prices of gasoline, diesel, electricity and E85 (Per gallon of gasoline equivalent (GGE))



Source: US Department of Energy, "Alternative Fuels Data Center," http://www.afdc.energy.gov/fuels/prices.html.

*Electricity prices are reduced by a factor of 3.4 because electric motors are approximately 3.4 times as efficient as internal combustion engines.

THE NUMBERS IN DETAIL: OIL AND ELECTRIC VEHICLES

Currently the only serious competitor for gasoline in its ground transportation role is the battery electric vehicle. Electric vehicles (EVs) powered by electricity from nonfossil sources are the main prospect for reducing greenhouse gas emissions from the transport sector—although currently electric vehicles are powered largely by electricity from fossil fuels, as these are the source of most electric power in industrial countries. Battery-powered EVs are currently more expensive to buy but less expensive to run than vehicles with internal combustion engines. A lot of the extra capital cost comes from the cost of batteries, which is falling fast, so the gap may narrow over the next five years. But at present the choice of a battery electric vehicle is a bet that fuel cost savings will offset the greater capital costs. Gasoline is far more expensive per mile driven than electricity, so the fuel savings depend on the price of gasoline and the number of miles driven.

At a gas price of $2.76 per gallon, a typical US price as of August 2015, someone who drives 15,000 miles annually will spend about $1,850 per year on gasoline if the vehicle gets 22.5 miles per gallon. At a price more typical in Europe, $6 per gallon, the fuel cost is twice this much, $4,000. However, fuel economy in Europe is generally 30 miles per gallon, making the fuel costs of 15,000 miles $3,000. Electricity to charge an electric vehicle and run it 15,000 miles will cost about $600 at 15 US cents/kWh, a typical price in the United States. In Europe a typical price would be closer to 25 US cents, giving an electricity cost of $900. So in the United States, the potential savings are about $1,250 per year, and in Europe closer to $3,100 or $2,100 depending on the fuel efficiency of the benchmark gasoline vehicle. These savings scale directly with the price of gasoline.

The cost of an EV is generally around $5,000 higher than a traditional gasoline-powered vehicle, though this can be affected by tax deductions and other subsidies. In this case the additional cost can be recovered at US gasoline and electricity prices in about four years, assuming 15,000 miles driven annually and 15 US cents/kWh. In Europe the additional capital costs could be recovered in two to three years.

The conclusion is that in Europe, EVs should remain competitive with internal combustion engines getting up to 30 miles per gallon with fuel prices of about $6 per gallon and an annual mileage of 15,000. However, European auto manufacturers are now offering a wide range of small vehicles that can easily surpass 30 miles per gallon and are therefore less costly than electric vehicles. Cost is of course not the only factor affecting the adoption of electric vehicles. Range, charge time, and availability of charging stations are all major issues, so cost parity is no guarantee of market penetration. In the United States, gasoline prices are so much lower that it is harder to justify the use of EVs on economic grounds. However, the fact that in the United States most gasoline-powered vehicles are so inefficient, returning very low gas mileage, boosts the competitiveness of EVs.

CARBON PRICING

Carbon prices have been widely recommended as a response to the threat of climate change and are slowly emerging onto the policy stage. In California and in the Northeastern states that are members of the Regional Greenhouse Gas Initiative, cap and trade systems for CO2 emissions have effectively put a price on carbon, and in the European Union such a price has been part of reality for about a decade. Any form of restriction on, or charge for, carbon emissions will clearly make oil less competitive with the alternatives. A tax of $25 per ton of CO2 would add 21 US cents to the cost of a gallon of gasoline, not a negligible amount but nonetheless not enough to alter the conclusions about transportation reached earlier in any substantial way. A tax in the region of $50 could probably be justified economically, slightly above US government estimates on the social cost of carbon, which would raise gasoline prices by 42 US cents. This could be big enough to have an impact on fuel choices, though it is still small relative to the price swings to which retail customers have become accustomed. When it comes to electricity generation, the effects of a carbon tax within the likely range are small: a $25 tax on each ton of CO2 emitted would raise the price of electricity from oil by about 2 cents. This would make oil less competitive, but not radically so.

THE NUMBERS IN DETAIL: OIL AND RENEWABLE ELECTRICITY

The cost of producing electricity is generally measured by its levelized cost: the levelized cost of electricity (LCOE) is the price at which it has to be sold to break even; it is the long-run average cost. There are many estimates of the LCOE of power from renewable sources, the most recent being one provided by Lazard. Lazard estimates the LCOE of power from wind as in the range of 3.7 to 8.1 US cents/kWh. Where in this range a particular installation falls depends on how strongly and how consistently the wind blows at its location: the low end applies to the high plains of the United States and to Hawaii. Lazard estimates the LCOE of power from thin-film solar as ranging from 7.2 to 8.6 US cents/kWh, with the low end relating to utility-scale installations with a single-axis tracking system. They expect the low-end cost to fall to 6 cents/kWh by 2017.

There are two points to note about these LCOE estimates. One is that they are without subsidies: they do not allow for any subsidies such as the investment or production tax credits or the sale of renewable energy certificates. The second is that the intermittency of renewable sources detracts from their commercial value and imposes costs on the utilities that use them. There is some dispute about the size of these costs, but a reasonable estimate seems to be no more than 1 US cent/kWh. Another factor to take into account is the time of day at which power is available, as the market price of power varies over a twenty-four-hour cycle, generally being greatest at peak demand in the afternoons in summer. This is close to when the output of solar power stations is at its peak: solar output generally overlaps with the maximum price of power, and so this enhances its value. Wind, in contrast, often peaks at night, when prices are low. Figures for Germany suggest that solar power is worth 16 percent more than the average kilowatt-hour, and wind power 6 percent less because of these timing factors.

Taking all of these factors into account, we estimate that in order to be competitive with renewable sources, it is necessary that electric power from oil cost no more than 6–8 cents/kWh.

As a comparison, power from natural gas, which is clearly competitive with renewables, costs in the range of 6.1–8.7 cents/kWh in the United States (but much more in other countries: gas is about $3 per mmBtu in the United States but $10–18 in most other industrial countries). Gas turbines have a symbiotic relationship with renewables: the intermittency of the latter means that they need to be backed up by a power source that can be switched on and off rapidly, and gas meets this condition uniquely well in the United States. In other countries, in particular in northern Europe, hydropower is used in this way.

Both gas and oil produce greenhouse gases when burned, so that both would be disadvantaged by a policy that restricts, or places a price on, greenhouse gas emissions. The European Union and several regions of the United States now have prices on the emissions of greenhouse gases, so that the cost of oil-fired electricity would have to be lower than we calculate here to be competitive in these locations. The cost estimates are summarized in Table 1.

To calculate the LCOE of power from oil, we need to know the capital costs of oil-fired power stations, the operating costs, and the amount of oil needed to generate a kilowatt-hour. This data is available from the Energy Information Agency of the US government and from the International Energy Agency. The calculations indicate that the LCOE of electricity from oil, before allowing for any costs associated with emission of greenhouse gases or any other pollution-related costs, is roughly 14 US cents/kWh if the price of oil is $50 per barrel. At $40 per barrel, it is 11.5 cents, and for the LCOE to be at the 7-cent level needed to be competitive with renewables, the price has to be between $15 and $16 per barrel. Such a price currently appears unlikely, and if achieved, would probably not be sustainable for long. Only Middle Eastern producers could make money at this level, so oil production would fall rapidly, driving up the price. If the price of oil were to return to its historical level of $100, then the LCOE would rise all the way to 23 cents/kWh. Table 2 summarizes these conclusions.

Table 1: Cost data for various electric power sources

Energy Source	**LCOE in US Cents/kWh**	**Notes**
Wind	3.7–8.1	Penalty for intermittency and timing
Solar	7.2 up	Penalty for intermittency, premium for timing
Gas	6.1–8.7	Penalty for CO_2 emissions

Source: Lazard, see endnote 14.

Table 2: The LCOE of oil-fired electric power at various oil prices

Price of oil $/bbl	**LCOE US c/kWh**
100	23
50	14
40	11.5
15.5	7

Source: IEA data, authors' calculations.

Even without going into detail on the calculations, it is possible to give an intuitive sense of why the numbers come out like they do. Producing a kilowatt-hour requires the combustion of 0.002 barrels of oil, which at $50 per barrel costs about 10 cents, already above the range in which oil could be competitive with renewables, even before the inclusion of capital or operating costs.

As wind and solar power stations produce at zero marginal cost, once constructed they will always be used in preference to any fossil fuel, oil included. So even if oil-fired power stations were to be built, wind and solar would be dispatched in preference.

Although low oil prices will not lead to oil displacing renewable energy in electricity generation, it is possible that they will lull the public into a sense of security about energy issues, so reducing the political pressure to displace renewables and support energy research and development.

However, it should also be noted that the majority of the American public has been in favor of investment in research and development in the field of renewable energy. A 2014 Yale study showed that an average of 77 percent of Americans are in favor of funding research on renewable energy resources, and 61 percent of Americans are even in favor of requiring utilities to produce 20 percent of their energy from renewable resources.

In drought-ridden regions, the fact that renewables need little water could impact their competitiveness in the future. Roughly 49 percent of water withdrawals (fresh and saline) in the United States can be attributed to thermal electric power plants. The water consumption of wind and solar energy is only a fraction of the water consumption of any conventional energy type. Recently the cost of a gas plant built in California by General Electric was raised because GE had to pay to upgrade the irrigation systems in a nearby town to offset the water use of their new gas plant.

A final point about competition between oil and renewables is that in many US states the use of renewables is mandated by Renewable Portfolio Standards (RPSs), requiring a certain fraction of electricity produced to come from renewable sources independent of the cost of this. These mandates mean that there is no price competition for renewable energy up to the point where the RPS requirements are met. In other countries, feed-in tariffs guaranteeing the purchase of all renewable energy produced at a fixed price also serve the purpose of insulating these energy sources from price competition.

The conclusion from this analysis of the numbers, summarized in Table 2, is that, provided oil prices remain above $40 per barrel, the cost of electricity from oil could never come below about 12 US cents/kWh, or its equivalent in other currencies. Provided that the cost of solar or wind power is less than 10 US cents/kWh or equivalent, these energy sources will remain competitive. Oil prices are close to being uniform worldwide and are unlikely to be below this level except in oil-producing countries that subsidize oil consumption. And renewable technologies are also uniform worldwide. The only significant difference is that the intensity of solar radiation falls off as latitude increases, so that the output of a given area of solar cells falls and the cost per kilowatt-hour rises correspondingly. So we can expect solar PV to be less competitive at higher latitudes.

Another issue to be considered is whether lower oil prices could affect the prices of other fossil fuels that compete with renewables in the power sector. For example, in several regions around the world, natural gas has traditionally been traded at prices linked to the price of a marker crude, so that low oil prices have automatically led to low gas prices. This makes gas more competitive with solar PV and wind as power sources. However, even allowing for the effect of oil prices on gas prices, there is no industrial country where gas prices are lower than they currently are in the United States (roughly $3 per mmBtu). And even in some parts of the United States, gas cannot undercut renewables despite the competitive pricing.

There are connections between the production of oil and gas in the United States, however, and this would likely be where important implications of lower oil prices on renewables would occur. Oil and gas are often produced together, as in the case of associated gas produced as a by-product of oil extraction. Both oil and gas can be produced through hydraulic fracturing (fracking) operations. In the case of associated gas, a drop in oil prices will reduce oil production and lead to a drop in associated gas production, and hence higher gas prices. But in the case of fracking, lower oil prices will lead to a redirection of rigs from oil fields, which could then be redirected to pure natural gas areas, potentially raising the supply of gas and lowering its price. However, the lower the natural gas price, the less economic marginal wells become. Which effect dominates will vary by region: in most regions, more gas is produced as associated gas than by fracking, so there the balance would most likely be an increase in gas prices. However, in the United States, gas production from fracking exceeds the volumes produced as associated gas, so this may lead to downward pressure on prices. A full analysis of the impact of lower oil prices on US natural gas production is beyond the scope of this paper, however.

CONCLUSION

Low oil prices could in principle affect the progress of renewable energy in several ways–by competing with biofuels as gasoline replacements in transportation, by making vehicles powered by internal combustion engines more competitive with electric vehicles, and by potentially lowering natural gas prices. Low oil prices have already reduced the appeal of biofuels and of electric vehicles. Biofuels and electric vehicles can still be less costly than their traditional competitors, but the margin is now very fine. The main question in this sector is the speed of development of second-generation biofuels, and whether their production can be scaled up economically. The current production of biofuels from foodstuffs uses tremendous amounts of water, has driven up the cost of food, and has a bad energy budget. Therefore, in this regard, low oil prices might help to slow down the growth of an inefficient part of the renewables market.

While oil is used in only a small fraction of power generation in the United States and globally, a comparison of costs shows that even at current lower levels, oil will not compete with renewable energy sources in the generation of electric power. For oil-fired power stations to be competitive, oil prices would have to fall to unsustainably low levels—around $15 per barrel, a price level at which the majority of oil producers would be losing money. Furthermore, other factors might play into electric capacity planning and investment. Access to water or the price uncertainty for fossil fuels might be equally potent concerns when investing in new electricity generation.

Because little oil is used to generate electricity, the primary impact oil prices will have on the competitiveness of different electricity fuels is through its impact on natural gas, which is used to generate 27 percent of electricity in the United States and around 22 percent globally. The impact of low oil prices on natural gas prices can cut in both directions. In some regions of the United States where gas is now very expensive, there will be a drop in gas prices because of the way contracts are written (although there is a general expectation that this aspect of contracts could change). In other regions, the supply of associated gas may fall, and prices may rise, as oil production is cut back. But in yet other regions, resources may be redirected from fracking for oil to fracking for gas, leading to an increase in supply and a drop in prices.

NOTES

1 Absent a breakthrough in carbon capture and storage technology.

2 US Energy Information Administration, "What is electricity generation by source?" March 31, 2015, http://www.eia.gov/tools/faqs/faq.cfm?id=427&t=3. International Energy Agency, "2014 Key Energy Statistics, "http://www.iea.org/publications/freepublications/publication/keyworld2014.pdf.

3 Environmental Protection Agency, "Renewable Fuels Standard," http://www.epa.gov/OTAQ/fuels/renewablefuels/.
US EIA, "Few transportation fuels surpass the energy densities of gasoline and diesel," http://www.eia.gov/todayinenergy/detail.cfm?id=9991.

4 US EIA, "Few transportation fuels surpass the energy densities of gasoline and diesel," http://www.eia.gov/todayinenergy/detail.cfm?id=9991.

5 Don Hofstrand, Iowa State University—Extension and Outreach, "Ag Decision Maker, D1–10 Ethanol Profitability," 2015.

6 Argus Americas Biofuels, 22 May 2015, https://www.argusmedia.com/Methodology-and-Reference/Key-Prices/~/media/3D4572EA5B7D4E538B62F49E9030438E.ashx.

7 Ethanol, like wind and solar, is to some degree protected from price competition by regulations in the United States. The Renewable Fuel Standard 2, part of the Energy Independence and Security Act of 2007, set minimum amounts of ethanol and other biofuels to be blended into transportation fuels. Because the use of biofuels is dictated largely by the need to comply with these regulations, competition from oil is unlikely to affect biofuel use. See "The Renewable Fuel Standard: Issues for 2014 and Beyond," Congressional Budget Office, available at https://www.cbo.gov/sites/default/files/45477-Biofuels2.pdf.

8 Not all electric vehicles are battery operated: fuel cell vehicles are also powered by electric motors. As fuel cell vehicles are a negligible presence in the market, from now on we will just refer to electric vehicles and mean battery electric vehicles.

9 British Columbia also has a carbon tax at the rate of $30 Canadian per ton of CO2 emissions. This tax was introduced in 2008 at a rate of $10 Canadian per ton.

10 Figures from Resources for the Future, at http://www.rff.org/centers/energy_and_climate_economics/Pages/Carbon_Tax_FAQs.aspx#Q10. Burning a gallon of gasoline releases about 20 lbs of CO2.

11 The US Environmental Protection Agency estimates the social cost of carbon at $40 per metric ton of CO2 (in 2014 dollars) for 2015, and $47 per metric ton in 2020. EPA, "The Social Cost of Carbon," revised July 2015, http://www.epa.gov/climatechange/EPAactivities/economics/scc.html.

12 Authors' calculations.

13 It would raise the price of power from coal by about $0.02/kWh.

14 The Lazard data was accessed at http://www.lazard.com/media/1777/levelized_cost_of_energy_-_version_80.pdf on July 30, 2015. Another source of estimates is the UN Intergovernmental Panel on Climate Change's special report on renewable energy at http://srren.ipcc-wg3.de/. The two sets of estimates are in close agreement on matters that concern the present report.

15 Even lower figures have been quoted outside the United States: "Dubai set a new global benchmark in December 2014: at 5.84 US cents per kW hour, the bid for Dubai Electricity and Water Authority's 200 MW solar PV plant was cheaper than oil at US$10/barrel and gas at US$5/mmBtu." National Bank of Abu Dhabi, "Financing the Future of Energy: The Opportunities for the Gulf's Financial Services Sector," March 2015. http://www.nbad.com/content/dam/NBAD/documents/Business/FOE_Full_Report.pdf.

16 These can reduce the LCOE by several cents/kWh.

17 See Stefan Reichelstein and Anshuman Sahoo, "Time of Day Pricing and the Levelized Cost of Intermittent Power Generation," Steyer-Taylor Center for Energy Policy and Finance, Stanford University, April 2013, and references therein.

18 Lion Hirth, "The Market Value of Renewables," European University Institute, January 2013, http://cadmus.eui.eu/bitstream/handle/1814/27135/RSCAS_2013_36.pdf?sequence=1.

19 US Energy Information Administration, "How much coal, natural gas, or petroleum is used to generate a kilowatt-hour of electricity?" http://www.eia.gov/tools/faqs/faq.cfm?id=667&t=6. International Energy Agency, "Projected Costs of Generating Electricity, 2010 Edition," http://www.iea.org/publications/freepublications/publication/projected_costs.pdf.

20 Yale Climate Change Opinion Maps, http://environment.yale.edu/poe/v2014.

21 NRDC, "Power Plant Cooling and Associated Impacts: The Need to Modernize US Power Plants and Protect Our Water Resources and Aquatic Ecosystems," IB:14-04-C, April 2014, http://www.nrdc.org/water/files/power-plant-cooling-ib.pdf, p. 4.

22 Pacific Institute, "Water Scarcity and Climate Change: Growing Risks for Business and Investors," February 2009, http://pacinst.org/wp-content/uploads/sites/21/2014/04/growing-risk-for-business-investors.pdf. Solar and wind plants use 0.0001 cubic meters per megawatt hour, while coal, oil, and gas plants use respectively 2, 4, and 1 m^3/mWh.

23 Personal communication with the authors.

24 In particular in Asia, where gas is generally over $15 per mmBtu, many times more expensive than in the United States.

25 US Energy Information Administration, "Natural gas summary," http://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm.

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