The Kaya Identity in Energy Forecasting

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In response to shareholder interest in greater transparency, oil industry participants issued reassuring forecasts about the role of fossil-fuels by 2040. While differing in energy demand analysis, these forecasts had similar, status-quo predictions on energy intensity and fossil fuels' share of total energy. The forecasts, however, failed to consider the effects of their own alternative energy projects as well as four key contributors to oil market instability; (1) responses to global warming, (2) mandates to write off non-economic reserves, (3) oligopolistic oil pricing, and (4) technological change. All of these instabilities converged in 2020, causing industry forecasts to be outdated.

Keywords: Kaya identity, forecasts of energy sources, GDP, carbon intensity

INTRODUCTION

Concerns about global warming have sparked energy forecasts through 2040 by major oil companies, energy trade associations, and energy think tanks. An examination of several of these recent forecasts suggests that a consensus was reached about how energy demand would be satisfied. However, closer examination of these forecasts shows that they essentially assumed that the share of energy provided by different energy sources would not be much different from the past decade. Not only is such a conclusion inconsistent with estimates of what must be done to curb global warming, but as recent experience with the Covid 19 pandemic is showing, it provides a false sense of security about the stability of the energy market.

A widely used equation provides a tool to analyze the assumptions behind different energy forecasts. This tool is the Kaya identity, which depends upon four sources of data that most forecasters provide in explaining their forecasts; population, per capita GDP, energy intensity, and carbon intensity (section 1- The Kaya Identity). When comparing of forecasts, wide differences are found in projections of population and per capita GDP, variables that determine the demand for energy, but the forecasters are in puzzling agreement about one variable: energy intensity, which reflects the technology used to supply that demand (section 2- A Puzzling Consensus). A comparison of forecasts of the shares of different energy sources for 2040 reveals that they are making similar forecasts and those predictions for 2040 that mirror the shares of energy sources in 2017 (section 3- Stability in the Shares of Different Energy Sources). That will not meet the targets set in the Paris Agreement to limit global warming, implying most forecasters are not explicitly examining scenarios where governments intervene to meet such targets (section 4- Forecast Failure).

THE KAYA IDENTITY

It is not an easy task to predict the future of fossil fuels over long time horizons. Many models such as Data Envelope Analysis (DEA), Logarithmic Mean Weight Division (LMD), and the Kaya Identity (Kaya and Yokobori 1997) can find the trend of carbon dioxide emissions with respect to fossil fuel consumption. Recent energy forecasting has relied upon and provided supporting data on the use of the Kaya Identity, which facilitates comparisons between the prognoses of different companies.

The Kaya Identity is a straight-forward mathematical equation that relates economic, demographic, and environmental factors to estimate global carbon dioxide (CO2) emissions from human activities. The equation is expressed as follows:

$$CO_2 = (\text{Population}) \times (\text{Per Capita Income}) \times (\text{Energy Intensity}) \times (\text{Carbon Intensity}) \quad (1)$$

- Per Capita Income = GDP/Population
- Energy Intensity = (Total Energy Expenditure)/GDP
- Carbon Intensity = CO_2/(Total Energy Expenditure)

When multiplied together the first two components equal the GDP, which is highly correlated with carbon dioxide emissions. For example, in the time between 1750 and 2019, the global population increased to 7.7 billion from 791 million (United Nations 1992). In the same period, CO2 concentration increased from 280 ppm to 414.7 ppm (National Oceanic and Atmospheric Administration 2019). Similarly, according to Jaunky (2011) , a 1% increase in GDP generated an increase of 0.68% in CO2 emissions in the short-run and 0.22% increase in the long-run.

Although the Kaya Identity provides strict proportionality between GDP and carbon emissions, the correlation is not perfect. This is due to the changing energy intensity both across countries and through time. The third factor of the Kaya Identity is energy intensity which is a relationship between energy consumption and GDP. The Energy intensity index is the amount of energy consumed to produce a given amount of economic output. The index can vary from country to country depending on the energy-efficient infrastructure, complicating attempts to provide a single measure for the entire world (Wang et al. 2015) . Even without government intervention, energy intensity has declined through time as more efficient technologies reduce energy waste. Energy intensity is therefore reflecting the technologies available for supplying the energy needed to produce the GDP. When the energy intensity is multiplied by the product of the first two variables of the Kaya Identity, the result is a measure of the total energy consumed by the economy.

The final variable in the Kaya identity is carbon intensity, which is the rate of carbon emission per unit of energy consumed. The burning of fossil fuels has a scientifically reproducible rate at which the energy from burning fuels can be converted into emissions of carbon dioxide. The rate is referred to as Carbon Dioxide Emission Coefficient or “carbon intensity.” These rates are invariant with respect to each different kind of carbon fuel, but when different carbon fuels are aggregated, as they often are in the Kaya Identity, the “carbon intensity” in the identity is a weighted average of the carbon dioxide emission coefficients. As the shares of carbon fuels used to produce energy change, the “carbon intensity” changes. When the carbon intensity is multiplied by the product of the first three variables of the Kaya Identity, the result is a measure of the total carbon emissions produced from consuming fossil fuels.

To see the relative importance of the four variables of the Kaya Identity, Table 1 (United Nations 2019; U.S. Energy Information Administration 2019a,b,c) shows their percentage change from 2010 to 2019 and across countries in relation to the macroeconomic quantities of GDP, energy consumption, and carbon emissions.

TABLE 1
VARIATION IN KAYA IDENTITY VARIABLES THROUGH TIME AND ACROSS COUNTRIES

KAYA IDENTITY VARIABLES	WORLD	OECD	NON-OECD	AFRICA	INDIA	CHINA
% POPULATION	11%	6%	12%	25%	11%	4%
% PER CAPITA GDP	23%	13%	36%	7%	64%	80%
% ENERGY INTENSITY	-14%	-14%	-16%	-6%	-16%	-27%
% CO_2 INTENSITY	-7%	-9%	-6%	-5%	1%	-14%
RELATED MACRO VARIABLES						
% GDP	37%	20%	52%	34%	82%	87%
% ENERGY CONSUMPTION	17%	3%	28%	26%	53%	37%
% CARBON EMISSIONS	9%	-6%	20%	19%	55%	18%
NOTE: % INDICATES THE PERCENTAGE CHANGE IN A VARIABLE FROM 2010 TO 2019						
THE FORMULAS TO DERIVE THE LAST THREE PERCENTAGES IN TERMS OF THE FIRST FOUR ARE:						
%GDP=(1+%POPULATION)*(1+%PER CAPITA GDP)-1						
% ENERGY CONSUMPTION=(1+%GDP)*(1+%ENERGY INTENSITY)-1						
% CARBON EMISSIONS=(1+%ENERGY CONSUMPTION)*(1+%CO_2 INTENSITY)-1						

In examining the energy forecasting models with the Kaya Identity breakout in Table 1 we can see the relative importance of population and per capita income in contributing to GDP growth. For example, under the "World" column, more than two-thirds of the percentage GDP growth of 37% is made up by the percentage growth in per capita GDP of 23% relative to the 11% growth of population from 2010 to 2019. But in China, almost all the 87% growth in GDP comes from a growing per capita income of 80% from 2010 to 2019. The energy forecasters examined here all carefully set out their assumptions about the first two variables of the Kaya Identity because of such wide variation across economies and through time.

Energy intensities also vary across countries as economies rely on different technologies and sources of energy. In Table 1, the percentage changes in energy intensity are negative, reflecting the movements of markets toward economizing on energy use. Countries like China have been able to reduce energy inefficiencies by greater percentages than other countries, but no country has been able to offset the growth in energy consumption by such economizing, as shown by the "energy consumption row" in the table. Almost all forecasters separate India and China from the rest of Asia in making their forecasts, and Table 1 shows why. Both countries have similar GDP growth rates (China with 87% and India with 82%), but China's 27% decline in energy intensity outpaced India's 16% decline. As a result, China's growth rate in energy consumption (37%) is less than India's (53%).

The percentage decline in carbon dioxide intensities of different countries are negative, smaller, and generally more stable than energy intensities. Nevertheless, important differences in the percentage change of carbon dioxide intensities reflect the differing efforts of countries in successfully switching away from fossil fuels. While China is switching to electrical vehicles which lowers dependence on oil and lowered their carbon dioxide intensity by 14% from 2010 to 2019, India has actually become more reliant on fossil fuels with a 1% rise in carbon dioxide intensity. As a result of the last two variables in the Kaya Identity, India has a growth rate in carbon pollution that is more than double that of China's.

Implicit in Table 1 are narratives about the macroeconomic and technological influences on energy consumption and carbon pollution. Perhaps the most important of these narratives is the overwhelming importance of per capita GDP in explaining both energy growth and increasing carbon dioxide pollution.

The most frustrating implicit assumption is the little change in energy intensity and carbon dioxide intensity relative to population and per capita GDP growth. Between 2000 and 2019 global carbon dioxide emissions from the combustion of fossil fuel increased by nearly 9% (U.S. Energy Information Administration 2019) from 32443MMmt to 35332MMmt. The OECD is the only region that saw a decline in emissions during the period as the result of improvements in a cleaner primary fuel mix which offset a relatively modest population and per capita income increases. In the non-OCED region, there was a rapid growth in per capita income and, to a lesser extent, population growth, which overwhelmed a nearly 16% improvement in energy intensity.

Each of the forecasters examined here must set out such narratives about 2040. The differences in their forecasts of the four variables in the Kaya Identity give clues as to the differences in their narratives.

A PUZZLING CONSENSUS

In 1992, concerns about global warming led to the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) to set up a framework in which to discuss country goals for combatting global warming. After 23 years a "Paris Agreement" was agreed to with 195 signatories that set a goal to keep temperature increases to 1.5o Centigrade above preindustrial levels. The International Energy Agency (IEA) has collected information and conducted forecasts that keep track of energy usage and carbon emissions. The template they chose for their forecast in their 2018 World Energy Outlook has been widely adopted by many forecasters. Major oil companies including Exxon, BP, Equinor, and OPEC were under pressure concerning the value of reserves in light of possible cutbacks in fossil fuels, and they issued forecasts to reassure stockholders or other interested parties about the viability of their reserves.

Table 2 (IEEJ Outlook 2018; Exxon 2019; BP Energy 2019; Equinor-Energy Perspectives 2019; IEA World Energy Outlook 2019; IEEJ Outlook 2019; OPEC World Oil Outlook 2019) assembles the forecasts of three major oil companies, the International Energy Agency (IEA), a representative (Institute of Energy Economics) of a major energy consumer (Japan), and a major producer (OPEC) to compare their 2040 forecasts. Three variables are compared for each forecaster: world gross domestic product (real GDP in 2010 USD), energy (Million tons of oil equivalent-Mtoe), and the corresponding energy intensity (Mtoe per 2010 USD). Each forecast for 2040 is divided by the forecast for 2017 to arrive at a "Ratio (2040/2017)" with which to compare forecasters' expectations.

TABLE 2
COMPARISON OF WORLD ENERGY FORECASTS

	Year	**Exxon**	**BP**	**Equinor**	**IEA**	**IEEJ**	**OPEC**	**Std. Dev.*/Average**
GDP (2010 $trillion)	2017	79	114	79	112	79	114	6.58%
	2040	150	236	143	241	152	237	
	Ratio (2040/2017)	1.90	2.07	1.81	2.15	1.92	2.08	
Energy (Mtoe)	2017	14173	13511	13764	14214	14004	14465	6.74%
	2040	17023	17866	15794	19636	18374	18268	
	Ratio (2040/2017)	1.20	1.32	1.15	1.38	1.31	1.26	
Energy Intensity (Mtoe per 2010 $trill.)	2017	179.41	118.52	174.23	126.91	177.27	126.89	3.77%
	2040	113.49	75.70	110.45	81.48	120.88	77.08	
	Ratio (2040/2017)	0.63	0.64	0.63	0.64	0.68	0.61	

*Coefficient of Variation (CV)

Even a cursory glance at Table 2 shows a wide disparity in GDP forecasts, reflecting differences in computing purchasing power parity and the base year used for measuring dollars. However, the ratio of 2040 to 2017 should eliminate most of these differences. Nevertheless, a measure of the differences in this ratio also shows substantial differences in the forecasts. The ratio of the standard deviation across the forecasts to the average is a simple indicator of the amount of agreement of the forecasts. For GDP, the standard deviation is 6.58% of the average size of the forecasts of the ratio of 2040 GDP to the 2017 GDP. For primary energy consumption, the ratio shows much an agreement among the forecasters at 6.74%. However, quite puzzling is that the forecasts of energy intensity show only a 3.77% disagreement about the ratio of energy intensity in 2040 to 2017.

Table 2 provides an interesting puzzle; while the energy intensity is almost the same across these forecasts, the variation across the two economic variables used to compute the energy intensity are quite different. The consensus on energy intensity in contrast to the variation in views about the economy shows where the primary analysis of the energy future is focused; on energy consumption, rather than the technology that delivers that energy.

Very few of the forecasters seriously build scenarios around alternative narratives of what might happen with technological changes or the agreement of governments to nudge energy markets away from fossil fuels. Notable exceptions among the forecasters examined here occur with British Petroleum, Equinor, and the IEA. BP summarizes “key points” of changes in specific areas of demand, including China’s attempt to grow away from energy intensive sectors, less use of plastics, lower carbon use in buildings and industry, and lower oil use in transport, but provides detailed regional breakdowns and shares of energy sources in two extreme scenarios, “evolving transition scenario” and “rapid transition scenario.” Equinor (Equinor-Energy Perspectives 2019) explains the three scenarios that it builds from regional breakdowns by energy source as follows:

The three scenarios in this report are constructed to embrace a wide range of possible future outcomes, building on different factors, trends, and developments we observe today, but where there is considerable uncertainty about future development. Energy markets in Reform build on recent and current trends within market and technology development rather than policy support, to be the main driver of change. Renewal represents a future trajectory, supported by strong coordinated policy intervention, that delivers energy-related emission reductions consistent with the 2^{o}-target on global warming. Rivalry describes a volatile world, where development and policy focus are determined mainly be geopolitics and other political priorities than climate change.

Table 3 shows dramatic differences between scenarios based on the willingness of governments to intervene in energy markets.

TABLE 3
THE EQUINOR SCENARIOS: REFORM, RENEWAL, AND RIVALRY

	Year	**Reform**	**Renewal**	**Rivalry**	**Std. Dev. Average**
GDP (2010 $trillion)	2017	79.06	79.21	77.98	10%
	2040	142.67	146.18	120.22	
	Ratio (2040/2017)	1.80	1.85	1.54	
Energy (Mtoe)	2017	13764	13546	13791	11%
	2040	15794	12936	16191	
	Ratio (2040/2017)	1.15	0.95	1.17	
Energy Intensity (Mtoe per 2010 $trillion)	2017	174.10	171.01	176.85	19%
	2040	110.70	88.49	134.67	
	Ratio (2040/2017)	0.64	0.52	0.76	

As in Table 3, the standard deviations/average of the 2040/2017 forecast ratio are taken. Because Equinor has set out different policy and technology assumptions in its three scenarios, energy intensity is nearly twice as variable as the other two macroeconomic variables. This is the kind of outcome that might have been expected in Table 2 from comparing the results of forecasters who were making very different assumptions from each other about the energy future. But those forecasters have arrived at a consensus forecast.

The consensus on energy intensity is that there will be a 36% (1-0.64) drop in world energy intensity between 2017 and 2040. Over the 10-year period from 2010 to 2019 there was a comparable 14% drop (see the entry in Table 1). If that rate were projected to 2040 it would be almost the same as the consensus forecast in Table 2. The consensus forecast seems to say that energy intensity will continue at the status quo; the market will decide the rate at which technology increases the efficiency of energy utilization.

STABILITY IN THE SHARES OF DIFFERENT ENERGY SOURCES

The consensus forecasting becomes even more clear when forecasts of specific energy sources are compared. If forecasters were making independent judgments about technologies and government interventions, they would not have made the same predictions about the shares that different energy sources would have in the future. Each energy source has a unique long-term trajectory due to differences in:

(1) Levelized costs of each energy source and the rate of change of those costs,
(2) The rate of technological change both in producing and consuming energy from the energy source,
(3) The speeds of adoptions of these new technologies, and
(4) The externalities inherent in energy production that characterizes each energy source.

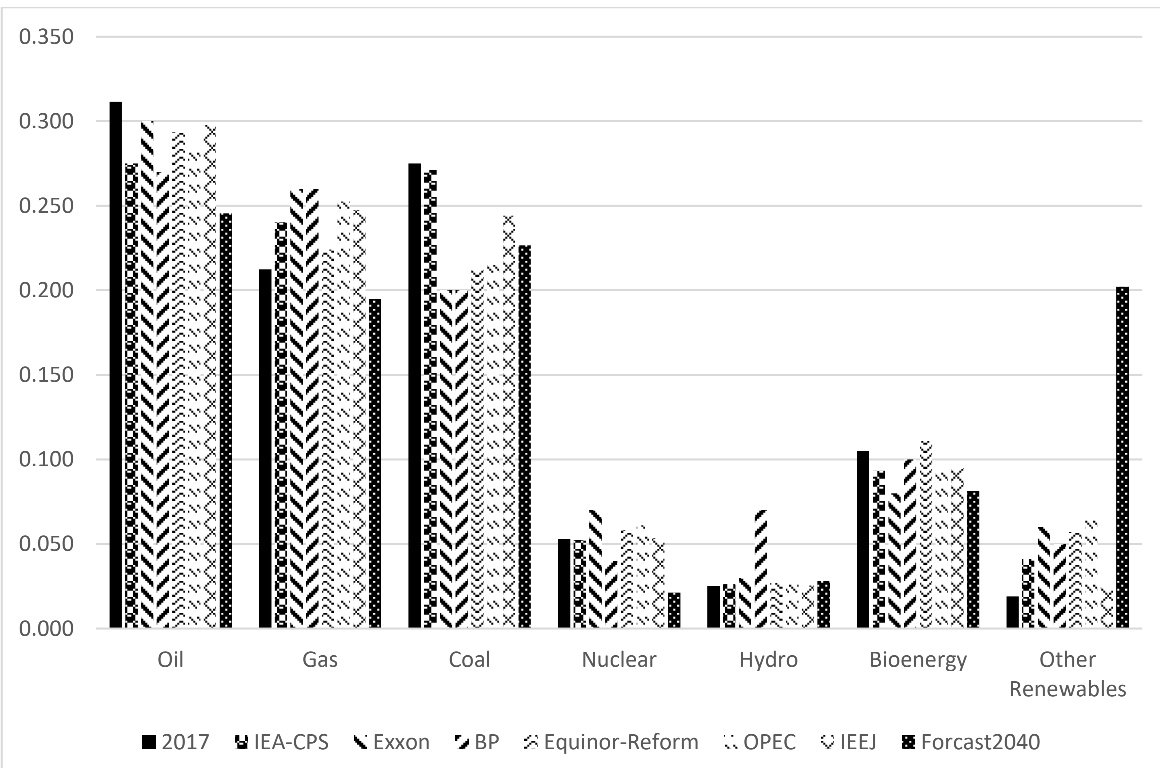
The Energy information Agency (Energy Information Administration 2020) measures the "Levelized cost of energy" (LCOE) of different energy sources as a comprehensive measure of all the costs involved in delivering a given quantity of electricity. The EIA computes the cost of producing a megawatt-hour (MWh) of electricity, allowing the costs of each energy source to be compared. While the technologies for fossil fuels can be counted in decades, many of the technologies for renewables and biofuels are more recent and are more rapidly descending the experience curve. While the Levelized costs of fossil fuels are generally stable, the Levelized costs of biofuels and other renewables have been declining and are projected to fall below the Levelized costs of fossil fuels. As these trends continue, it is to be expected that renewables will gradually substitute for fossil fuels.

Major technological changes, particularly in energy consumption, have an uneven impact on the different energy sources. When a fossil fuel producer supplies energy to satisfy energy demand only 32% of the energy in primary fuels is converted to net goods and services. This factor is referred to as the "energy conversion efficiency," the percentage of produced energy that actually is used. The other 68% is lost as "rejected energy," primarily in the form of wasted heat. The substantial energy loss from "rejected energy" varies across the consuming industries from 28.4% to 41.4%, nearly a 50% difference in efficiency. As progress is made in eliminating rejected energy, energy intensity falls, but the progress is not evenly distributed among the different energy sources. When hybrid vehicles, for example, reduce the rejected energy of gasoline engines, it substitutes energy sources used to produce electricity at the expense of oil. When buildings are designed with better insulation, they economize at the expense of fossil fuels used for heating and air conditioning. A forecaster cannot treat such technological change with an aggregate equation for the whole economy; predictions about the rate of technological change must be made by energy source and region.

Greater awareness of the externalities of the different energy sources has fed policy debates that have led to dramatic policy changes. Most importantly, the discovery of the dangers of nuclear energy has dramatically altered the willingness of governments to rely on that source of energy. Pollution from oil spills has limited deposits from which oil can be extracted and from the construction of pipelines to transport the oil. The pollution and earthquakes from fracking have caused states to prohibit that extraction technology. Each of the energy sources varies from having dangerous storage and transportation technologies such as pipelines to having little or no such costs. However, predicting government intervention in producing primary energy is difficult.

It is to be expected that independent forecasters would come up with different predictions about the shares of total energy provided by different energy sources. However, a comparison of the forecasters examined in Table 2 leads to a very different conclusion. Figure 1 contrasts the forecasts of the share of total energy provided by each of the energy sources by the same forecasters listed in Table 2. The first bar, shown in uniform black, shows the market share of each energy source in 2017. Next to that bar is the earliest forecast, made by the IEA, of the market share in 2040 followed by the forecasts of the same share by the three big oil companies (Exxon, BP, and Equinor) and OPEC. The second to last bar shows the forecasted market shares by the think tank for oil consumers (IEEJ). The very last bar, labeled "Forecast2040" extrapolates the growth rates of each of the energy sources from 2015 to 2040 based on the five-year annualized growth rate between 2010 and 2015, based on data accessible to the other forecasters at the time of their forecasts. This naïve forecast focuses only on the growth rate of each energy source without adjusting for expected demand in 2040 but is useful because it shows the changes that forecasters were seeing at the time, and how they nudge their forecasts toward the status quo, rather than where the changes are actually happening.

FIGURE 1
FORECASTS OF THE MARKET SHARE OF DIFFERENT PRIMARY ENERGY SOURCES



The largest disagreement among the forecasts occurs with "other renewables." The range of forecasts spreads over a large 17.8% of the total energy market. In other words, the difference between the maximum from the naïve 2040 forecast of the share of renewables and the minimum from the actual 2017 share of renewables is 17.8% of the total energy market. The growth rate of wind and solar power was very fast in the short period between 2010 and 2015. Without that forecast, the range between the forecasts of all other energy sources would be within 4.1% market share of each other in predicting the share of renewables for 2040.

As a result of its high prediction for renewables, energy shares must be lost somewhere in the naïve forecast. Particularly interesting are the energy sources for which it projects lower shares than any of the other forecasters. The 2040 forecast gives the minimum prediction of energy shares for both oil (24.5% of the total energy market) and natural gas (19.5%). All of the other forecasts are hovering within a range of each other of only 3% for oil and 3.6% for natural gas. The oil companies all believe that coal takes the hit and predict a lower share for coal than the naïve forecast predicts- but not much lower. While there is widespread agreement among the forecasters that coal's energy share falls by 2040 their forecasts range over a wide 7.1% of the total energy market. Based on relative growth rates of the different energy sources between 2010 and 2015, the naïve forecast suggests the dramatic expansion of renewables comes at the expense of fossil fuels. All of the other forecasters nudge their forecasts for oil and gas close to the energy shares that those fuels had in 2017 as if the growth of renewables was an aberration. And if there is any sector that is expected to lose energy share, it is coal. The forecasters just cannot agree on how much that loss will be.

Except for the naïve forecast, the oil companies and OPEC make the maximum market share predictions for the non-fossil fuels. Exxon predicts a larger share going to nuclear energy than anyone else. BP predicts a larger share going to hydroelectric power than anyone else. Equinor predicts a larger share going to bioenergy than anyone else. As our lone energy consumer, the IEEJ predicts the smallest shares going to hydroelectric power of anyone, and it also predicts the lowest use of renewables.

But these differences belie the consensus that these forecasters are showing for the market share of world energy predicted by 2040 for each energy source. While they are making very different predictions about the macroeconomic variables of population and per capita income with published information on their country-by-country assessments, they make nearly identical judgments about the shares that each energy source will provide in 2040. And those judgments are quite close to the shares experienced in 2017. Dismaying this consensus is the implication for global warming and the resilience of the energy market to major changes.

FORECAST FAILURE

Forecasting stable energy shares of fossil fuels, the oil companies were signaling that they were doubling down on their bet on fossil fuels and were not reassuring anyone about their willingness or ability to manage the contingencies they faced in the energy market.

This retrenchment into fossil fuels contrasted with sixty years of very clear strategic moves to compete with or own new sources of energy. In the early sixties when coal was becoming an alternative to oil, the oil companies began acquiring coal companies reaching a total market share of 30.1% in the coal market by 1989 (Reardon 1993). Simultaneously nuclear power was viewed as a backstop technology that could be used as fossil fuel reserves ran out (Nordhaus 1973). Five of the seven major oil companies acquired uranium deposits and three of them were actively mining and milling uranium for a combined market share of 54% of uranium mining and milling activity in the U.S. by 1971. The Ford Foundation estimated that the top eight energy companies, seven of which were oil companies, increased their market share of this new "energy market" from 19.7% in 1955 to 35% in 1970 (Ford Foundation 1974).

When the three-mile island and the environmental consequences of coal became apparent, the oil companies quickly divested their commitments to these alternative sources of energy. With the loss of control of international oil reserves, they retrenched to oil refining. However, as renewable energy sources have become competitive with fossil fuels, their response has been limited. ExxonMobil sets up a joint venture with Synthetic Genomics to genetically engineer photosynthetic algae to produce renewable crude from sunlight and has a significant market share in the new carbon capture and storage (CCS) technology (Exxon Mobil 2018). British Petroleum (BP) owns Lightsource BP, which has been a leader in American wind and solar power and has a joint venture with DuPont (**DowDuPont**) in next-generation renewable fuels (Chatsko 2018). Royal Dutch Shell recently invested in California solar energy business, an offshore wind farm in the Netherlands, a ride-sharing app start-up in London, a company that provides charging outlets for electric vehicles, a solar developer, Silicon Ranch, and an on-site power generation management company, MP2 Energy (2018). Chevron made small investments in projects spanning wind power, solar, and geothermal that can power a combined 113,000 U.S. homes (2018). Historically, when the oil companies saw the arrival of such new energy sources, they became major players in defining the widening energy market. With their considerable financial resources and expertise, the oil companies are certainly the most likely potential entrants into any of these alternative energy markets. However, these oil company investments, alternative energy has been piecemeal and pale in comparison to the enormous reinvestment projects in building oil reserves and refining capacity.

While these projects in alternative fuels are celebrated in the oil company forecasts, there is a puzzling disconnect between the rationale for those projects and the forecasts. If the alternative energy projects were conceived as a way of countering the uncertainties of depending solely on fossil fuels, then the oil companies would have constructed business plans or capital budgeting studies that explicitly defined the market conditions in which such projects might be profitable. For example, ExxonMobil's carbon capture and storage (CCS) technology is not something that utilities will be willing to buy unless governments require them to capture carbon. Exxon's forecast provides an opportunity to specify a scenario in which government intervention in electric power production increases the demand for CCS. Using the Kaya identity, the scenario could be compared to Exxon's status quo scenario detailed in its 2018 Outlook. Most importantly, in examining such a scenario, ExxonMobil could show how CCS would contribute to its own profitability and diversification strategy. By not including the underlying assumptions that justify its non-fossil fuel projects in its forecast narrative, there is a disconnect between Exxon's broad-brush discussion of different scenarios in the literature and the scenarios providing the foundations for its CCS and its joint venture with Synthetic Genomics. Without including the foundational scenarios to its ventures in its forecasts, Exxon is missing the opportunity to be fully transparent. The stockholders- and stakeholders- simply do not see the connection between a company's forecast and its strategic investments. A similar disconnect between scenarios discussed and scenarios actually used characterize the forecasts of the other energy companies examined here.

The examination of scenarios featuring larger energy shares for the renewables can accomplish more than transparency. The fossil fuel energy sources are endemically unstable with a lot of downside risk that can suddenly lower fossil-fuel company profitability and share of the energy market. The four destabilizing factors that are hardly mentioned in the industry forecasts and that caused those forecasts to be seriously outdated are: (1) policies to stem global warming, (2) the requirement to write off non-economic reserves, (3) the oligopolistic structure of oil pricing, and (4) volatile demand for energy due to technological change.

THE CONTINUED THREAT OF GLOBAL WARMING

The forecasts of fuel market shares in Figure 1 contrasts dramatically with the forecasts of what will have to happen if sustainable temperatures are to be achieved. The International Energy Agency (IEA World Energy Outlook 2018) has forecasted the energy sources that would have to be used to maintain a sustainable world average temperature only 2º Centigrade above preindustrial levels (referred to as the "sustainable 2ºC scenario" that complies with the objectives of the Paris Agreement). Table 4 provides the IEA's three-part set of forecasts: the historical years, 2000 and 2017 on the left, New Policies next (moderate case), Current Policies next (worst case) and finally the Sustainable Development, which is the sustainable 2ºC scenario. Notably, the fossil fuel share in the last scenario drops from the 81% level in 2017 to 60% in 2040. It is an essential path to success, but quite distinct from the predictions in Table 1 by the Energy Industry.

TABLE 4
WORLD PRIMARY ENERGY DEMAND BY FUEL AND SCENARIO (MTOE)

Primary Energy Source	2000	2017	2040		
			New Policies	Current Policies	Sustainable Development
Coal	23%	27%	22%	25%	12%
Oil	37%	32%	28%	29%	23%
Gas	21%	22%	25%	25%	25%
Nuclear	7%	5%	5%	5%	9%
Hydro	2%	3%	3%	3%	4%
Bioenergy	9%	10%	10%	8%	11%
Other Renewables	1%	2%	7%	5%	16%
Total	100%	100%	100%	100%	100%
Fossil Fuel Share	81%	81%	75%	79%	60%

Particularly important on the sustainability issue is the forecast on renewables. In Table 4 renewables do the major heavy lifting in replacing fossil fuels if sustainable development is to be achieved. However, in the industry forecasts in Table 1, while all industry forecasts exceed the share of energy in 2017, none of them come close to what would be needed for sustainable development shown in Table 4. It can be argued that the oil companies cannot be expected to do the kind of analysis of the feasibility of renewables being undertaken by the Energy Modeling Forum (Bauer et al. 2020) but their forecasts fail to reconcile the fast growth rates actually achieved by the renewables by 2015 (as in Figure 1), their own modest forecasts of that growth (again as in Figure 1), and the growth that would be necessary to reach sustainability (as in Table 4). An important part of the reconciliation will depend upon the willingness of governments to intervene in the energy markets to spur the use of renewables. At a minimum, the oil companies should include a scenario in their forecasts which details how such intervention could alter the demand for the fossil fuels.

WRITING OFF RESERVES

In 2013 former Vice President and Nobel winner, Al Gore, warned about the "carbon bubble." During the price spikes of 2012 to 2013, Gore was analogizing carbon assets to the subprime mortgages that had crashed in 2008 (Websdale 2013). A year later in 2014, almost on cue, the crude oil market crashed. Under the SEC rule (Title 17 → Chapter II → Part 210) the major oil companies had to write off oil and gas reserves a year later in 2015.

In the past, stockholders had gauged the health of the oil companies with the ability to replace reserves, but suddenly they were concerned that the companies might be caught with stranded reserves. At shareholder meetings, they voted through motions for greater transparency by the companies on reserve strategies. But oil prices rose again, and by 2017 the oil companies were posting large gains in such oil and gas reserves, as profits rose. The state of New York in the case, New York State vs. ExxonMobil, then accused the companies of inadequate reporting of the potential effects of climate change regulation on stock valuations, a case which they just recently lost (People of the State of New York v. Exxon Mobil Corporation 2018).

To reassure investors, the oil companies opined in their forecasts that there would be no major changes to demand. For example, in its Energy & Carbon Summary: Positioning for a Lower-Carbon Energy Future in 2018, ExxonMobil was responding to a shareholder resolution in 2017 that sought additional climate disclosures about the impacts of technology advances and global climate change policies on the company. ExxonMobil wrote:

Based on currently anticipated production schedules, we estimate that by 2040, over 90 percent of our year-end 2016 proved reserves will have been produced (Exxon 2018).

In reissuing its summary in 2020, ExxonMobil provided additional detail. Proved reserves are the main driver of intrinsic value of an integrated oil and gas company's upstream operations. …Since the 2°C Scenarios average implies significant use of oil and natural gas through the middle of the century, we believe these reserves face little risk from declining demand….Accordingly, the production of these reserves likely remains economic even under the 2°C Scenarios average.

While holding to its belief that its reserves had buyers, ExxonMobil was addressing the crucial issue that it had not mentioned in its 2018 Summary; whether or not those reserves would "remain economic" to extract. If oil prices would not hold, they might not remain economic to extract and would have to be written off before they could be used.

At the time they were writing this 2020 Summary (Exxon 2020) they had not seen the 2020 crash in oil prices when "OPEC+" (essentially, Russia and Saudi Arabia) failed to agree on production cuts to stem the crash in oil demand. ExxonMobil's reserves which they claimed "face little risk from declining demand" faced very big risks of being written off as was done both by BP for $17.5 billion of its reserves and Shell for $22 billion of its reserves (Inside Climate News 2020).

OLIGOPOLY

But this was not the first time that prices had been so dramatically affected. Since the Arab Oil embargo of 1973, the oil market has been controlled by an oligopoly. Like most oligopolies the participants can alter the price and the price reflects the vicissitudes of the interdependencies of the participants. Initially the formation of OPEC led to upside risks for oil prices, as in the case of the oil embargo of 1973 and 1978. But as members of OPEC exceeded their quota and OPEC failed to enforce them, the price volatility became characterized by downside risk with disagreements among the oil producers. Saudi Arabia disciplined the oil producers in 1985. The oil price drop in March of 2020 is only a reminder that such dramatic drops in prices can occur at any time.

VOLATILE ENERGY MARKETS REFLECTING TECHNOLOGICAL CHANGE

The worldwide recession of 2008 and the oil price drop of 2014-16 (World Bank 2018) showed how dramatic collapses in energy prices could occur from rapid changes in worldwide demand. The impact of Covid 19 on energy demand is a reminder of both how quickly price volatility can occur and how likely demand changes are to be permanent. Scenarios mentioned above by both Equinor and the IEA examine permanent demand changes beyond those of population and GDP.

Major collapses of prices may cut large permanent swaths through energy users tottering on the brink of collapse due to underlying market changes. Although it will be necessary to wait for the full quantification of the effects of Covid 19, such effects are qualitatively evident.

The premier change has been ushered in by the technologies allowing virtual meetings. Businesses have been forced to cut travel; judging by airline bookings, the cuts are well above 50% of pre-Covid levels. Educational institutions, medical institutions, many other business services, and retail are able to transact business online in ways that would scarcely have been predicted prior to the Covid 19 crisis and have been speeded up because of Covid 19.

Businesses have been forced to accommodate and experiment with more flexible ways of locating employees to get work done; as employees can work from home, traffic patterns and energy use will permanently become more efficient, and businesses will not have the same needs for heating office space or malls. Furthermore, the pandemic may provide the necessary opening for new technologies such as Electric Vehicles as gasoline engine businesses become less competitive.

While the industry forecasts may have temporarily reassured stockholders about the energy future, the events of 2020 have rendered them outdated, have renewed concerns about both demand volatility and the ability of the companies to manage new energy market. The evidence that the industry forecasts have reached a consensus says more about company incentives than it does about the likelihood that the status quo will continue for fossil fuels to 2040. The companies may be more worried about having more misleading predictions than their competitors rather than correctly forecasting what will happen to fossil fuels.

CONCLUSION

The oil industry forecasters during the period, 2014-2019, reached a consensus that fossil-fuel energy shares would be similar to the status quo by 2040. Using the Kaya Identity, it is possible to locate where the commonality of their forecasts lies. While they make very different guesses about population and GDP, which reflect expectations about worldwide energy demand, their forecasts have nearly the same predictions about energy intensity which reflects similar expectations about energy supply.

Most of the industry forecasts lock on a single scenario. This is puzzling since many of them invest in projects which would be justifiable in scenarios where alternative fuels play a larger role. Connecting their assumptions behind such projects to their forecasts would contribute to the transparency of both the forecasting and strategic planning of these companies.

Most of the industry forecasts believe there will be adequate demand to cover their reserves. The narratives that deliver explanations of the forecasts largely finesse contributors to instabilities of the oil market; (1) policies to stem global warming, (2) the requirement to write off non-economic reserves, (3) the oligopolistic structure of oil pricing, and (4) volatile demand for energy due to technological change. In 2020 all four sources of instability outdated the forecasts.

The great danger of the consensus forecasting around the stability of energy market shares is that it has reinforced the fossil fuel producers in reinvesting in fossil fuels. Reinvesting in fossil fuels comes at a great opportunity cost of the major fossil fuel producers; their failure to invest adequately in new sources of energy.

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