IICEC Energy and Climate Research Review

Executive Summary

The *IICEC Energy and Climate Research Review* provides an organized overview of recent energy policy research. The Review includes 68 studies and papers that collectively address global energy security, affordability and sustainability and shed light on the energy debate by illuminating its complexities.

With the gravity of the challenge in mind, the Review intends to capture the complexity of the energy debate from as many angles as possible bearing in mind that energy is a multi-disciplinary domain which requires in-depth analysis. Analyses that focus on only one dimension (e.g., engineering concepts) and neglect others (e.g., costs, business models or consumer acceptance) can be useful but may not be a sufficient for a balanced policy perspective.

The *Review* is organized by energy sectors and themes namely: fossil fuels, nuclear power, renewables, efficiency measures, energy technology and innovation, as well as climate policy and regional economies. We intend that the Review can efficiently provide energy professionals the benefits of many of the most important policy studies that they might not otherwise have the time to consider. We aim to foster to a wider appreciation of the global energy policy agenda by making these research studies more accessible.

The articles and reports in this Review have been selected considering their worldwide recognition, relevance, inclusiveness, originality, and the level of contribution to the policy agenda. Rather than providing a conclusive assessment and dictation of set of energy policies, the Review provides the reader with an opportunity to approach and analyze the articles, reports and policy papers from different perspectives.

Highlights on Natural Gas

As a fastest growing fossil fuel, natural gas is set to become the second largest source of energy following oil as of 2030, which is also expected to surpass coal consumption. The growth of LNG trade is enabling natural gas' expanding global role. Natural gas demand increased in all end-use sectors, spearheaded mainly by China and India with net imports expected to reach to that of the European Union. LNG trade has also led to changes in natural gas contracts and pricing. While natural gas has not achieved the status of a world-wide commodity such as marker grades of crude petroleum, that can be shipped anywhere in the world at a very low cost relative to value, regional natural gas

trading hubs have emerged, particularly in Europe. These hubs contribute to market depth, transparency and liquidity, although there is room for improvement for the Eastern European gas market. Establishing a Balkan Gas Hub, especially in Turkey, would not only increase the energy security, but would also make the regional market more competitive. While Russia would remain an important supplier, a trading hub would significantly erode the monopoly power of Gazprom and other state suppliers. The precedents set by EU competition initiatives to promote gas-on-gas competition, extended to South East Europe, would also provide significant new business opportunities especially if Turkey establishes a physical gas hub and trading exchange serving the region. Turkey is well placed to serve as a regional pricing point because of its extensive natural gas infrastructure and its increasing diversification of supply. These features make it uniquely able, among its neighboring countries, to host a physical trading hub. While other developments are needed to satisfy the preconditions for commodity trading, a Turkish gas trading hub could benefit Turkey, Europe and nearby natural gas exporters.

At a time of heightened risk of security of gas supply, the deployment of Floating Storage and Regasification Unit (FSRU) serves as a buffer to avert any unexpected supply shortages for gas importing countries. Among many other countries, Turkey has also joined FSRU with the aim of benefiting from the world's gas oversupply and diversifying its supply sources as well as reducing the vulnerability during the peak demand. Other than commissioning FSRU, Turkey has increased support for renewable and coal through new regulations. to further strengthen the country's energy supply security.

A new gas among LNG suppliers is emerging. As newcomer countries have brought abundant volume of gas into the market, gas consumer countries are benefiting from spot LNG that has risen to be a more significant share of the LNG market. Along with the decrease of destination clauses in newer LNG contracts, LNG becomes a commodity that can be acquired in short order from a well-organized market. As the global LNG market expands, with Asia being the biggest potential customer, the role of the newcomers, Australia and the USA are increasingly important and bringing much more liquidity, flexibility and integration to the market. From the consumer side of LNG, among major LNG consumer countries, Japan will be an important key player as Japan's global role in LNG has drawn increasing attention both as a consumer and an achiever of market liberalization.

Highlights on Petroleum

In the aftermath of the fallout from the 2014 oil price crash, there have been structural changes in the prospect of oil consumption from the demand side. In the supply side, tight oil has kept its resiliency. Nonetheless supply risks remain with heightened tension stemming from Libya, Nigeria and Venezuela still linger on posing an additional risk of long-term disequilibrium in the global oil market.

The U.S. has become a major key oil market supplier with an increasing ability of over-balancing the market with the tendency to keep year-on-year supply growth at least as high as demand growth. The larger oil stocks that have prevailed in recent years and the proven resiliency of unconventional oil production lessen the oil price consequences of even large unplanned oil outages. Oil security is achieved by avoiding the sharp and significant increases, as it is the "price spike" that damages the economies of industrial countries rather than an inability for refiners to acquire feedstock. The combination of larger-than-normal commercial stocks, IEA's emergency stocks and the ability of tight oil producers to quickly ramp up production that have currently created an era of relative oil security and, in real terms, low prices.

The main strength of the shale oil stems from the fact that cost cutting, well designing and efficiency measures have been at the center of the profitability with a motto of "the maximization of each dollar spent". Shale oil revolution still continues to reshape the world oil market, making the U.S. a key oil market supplier and one of the world's biggest exporters of refined petroleum products.

Shale revolution has put the U.S. at the forefront of the global oil market, and still holds optimistic future outlook as a robust demand increase from Asia suggests that there is a strong growth potential ahead. Nonetheless, the world oil market has not yet fully recovered from the 2014's collapse in oil prices and still carries the traces of the price shock. The lack of upstream investment would likely to be felt in the global spare capacity as of 2023 unless a modest recovery is revitalized.
The fundamentals of oil economy are changing due to, on the one hand, declining

Investments in complex conventional oil projects, declining production from mature fields and supply risks among several major oil exporting countries vs. expanding low-cost U.S. tight-oil production and uncertain prospects for a global economic recovery. At the time of this publication, OPEC will be challenged to raise current low prices without help from as stronger world economy. In the medium and longer term, a better economic picture could lead to a tighter oil market depending on how much U.S. unconventional oil supply may grow. Depending on a complicated interplay of many different and uncertain factors, a tight oil market, with greater oil supply risks, could re-emerge. If so, future unplanned oil supply outages could again cause large price spikes that would damage the economies of industrialized countries. Consequently, maintaining global strategic oil stocks remains a priority. Ensuring and coordinating strategic oil stocks remains a key responsibility of the International Energy Agency. It is also one of the reasons the IEA is engaging the large energy-consuming countries outside of the OECD. Over half of the world's oil consumption is outside of the OECD.

Highlights on Energy Efficiency

Energy efficiency has been the cornerstone strategy for secure, competitive and sustainable energy policies and investments that guarantee inclusive economic growth. To enhance energy security and to boost competitiveness and welfare while cutting carbon emissions, the strong deployment of energy efficiency measures is necessary.

Efficiency measures can be applied to transportation, residential and industrial sectors. The transportation sector provides one of the most transparent opportunities to improve energy efficiency. In fact, vast technological progress has been made to make the internal combustion engine (ICE) vehicle more efficient. However, most of the technological progress has been used to produce larger, heavier and more powerful vehicles while achieving only modest progress in overall fuel economy, or no improvement at all. Without technological progress, the current fleet of light-duty vehicles would have much lower fuel economies than they have. In past decades, the motivation to mandate improved fuel economy was to reduce oil consumption, especially after the 1970's "energy crisis." Subsequent decades of volatile, and often very low, oil prices reduced the policy pressure to improve fuel economy. With the more recent awareness of the dangers of greenhouse gas emissions, the United States, the European Union and other countries have set much higher fuel efficiency standards. They are also providing incentives for non-

ICE vehicles, especially battery-electric vehicles, as they can provide larger emission reductions than are possible by improving ICE fuel efficiency.

The first step in effective energy demand is improved energy efficiency. The building sector, in particular, lags behind with large untapped opportunities to save energy despite progress in lighting and appliance energy efficiency. For example, with conventional technologies, average air-conditioning efficiency can easily be increased or even doubled. With new financial support mechanisms and the adoption of obligatory schemes, large untapped potentials to improve building insulation and energy management can also be realized. However, effective policy measures to accomplish this have proved elusive. Reasons include the complex, and often local, regulation of the building sector. It can also be challenging to implement comprehensive building efficiency retrofits. While it is easier to regulate new buildings, they will remain a very small percentage of the total building stock for a very long time and, unfortunately, even these regulations are, in many places, not nearly sufficient.

Improvements in industrial energy efficiency could prove to be the most important the including iron and steel, paper and pulp, cement, petrochemicals, and glass industries. Adaption of best available technologies would significantly increase overall energy efficiency measures in all these industries.

Given that industry's share in global energy consumption accounts for approximately one third of the overall energy consumption, application of bold measures has become a prerequisite and of utmost importance for any government to mitigate carbon emissions. Nevertheless, current measures fall short of meeting the required conditions due to the existing difficulties in developing, implementing and deploying efficiency measures. Part of the problem is centered on the idea that there is a lack of understanding regarding the full benefits of efficiency measures and insufficient institutional backing.

Monitoring and verifying results are one of the key components of an energy efficiency investment for a successful implementation of energy efficiency. In addition, fiscal and financial drivers need to be the basis for creating a viable business case for efficiency. Measures such as tax breaks and guarantee schemes can be instrumental in initiating an increased volume of a broader and successful innovation program.

Among many other successful implementations of efficiency measure examples, it is worthwhile to mention that the EU has been the most determined example initiating strong policy measures targeting 20% of efficiency in 2020 and 30% in 2030. With respect to the defined target, the EU has not yet reached the target level despite the notable success measured in transportation, residential and industrial sector.

Energy efficiency remains the largest untapped "source" of energy. However, unlike marketing energy supply, it is not always easy to find a good business model for saving energy. Money is more easily made by producing energy for sale than by making the much more disaggregated needed investments to save energy, especially in the buildings and industry sectors.

Highlights on Renewables

Reduction in carbon emissions and local pollution, along with increased accession to energy, are some of the features characterized in the widespread deployment of renewable energy in recent years.

Renewable energy has been at the core of the climate policy. The landscape of renewable energy has been in transformation for some time and captured the attraction of all countries. In the International Energy Agency's World Energy Outlook 2018, it is stated that two-thirds of all new power capacity was brought by renewables. Of these, solar PV took the lead in growth. China and India accounted for the largest share of all the new capacity installation of renewables in 2018, becoming the world leaders in renewable energy use.

As the competitive ability of renewable sector increases and the cost of technology declines, renewable energy will continue to break the records of investment. Coupled with capacity increase and strong government subsidy programs, the share of renewable will continue to increase in electricity, heat and transportation sectors. Renewables enjoy a combination of factors that foster rapid growth: low cost, widespread government support, and scalable projects from household level distributed generation to giga-watt grid-scale installations. Governments and grid operators encourage renewables with "shallow connection policies" so renewable investor transmission investments are usually limited to making a connection to the closest grid node. Other consequently required investments are typically the responsibility of the grid operator. Likewise, small distributed generators often receive investment subsidies and generous buyback terms (e.g., "net-back metering"). Other

consequences of a more variable power generation are often also borne by thermal and other power plants that, as a result, operate at lower capacity factors and may need capacity payments to remain economically viable. The market and regulatory environments in which these developments are taking place are highly varied and can produce a variety of scenarios for power-sector investors. Besides increased renewables, the general trend is to increase load following power, electricity storage, smart meters, digitalization and other innovations. These are likely to meet the challenges to develop the electric grid of the future that will enable relatively high levels of variable renewable energy.

While wind and solar PV have consolidated its position in the power generation, biofuels have not affected the transportation sector to a comparable degree. There has been a lack of progress in developing "second generation" biofuels that are not produced from food crops such as cane sugar, grains and vegetable oils. The most promising outlook for renewable energy in transportation now comes from the uptake of battery electric vehicles (BEVs). Ideally, this would couple the transport sector to emissions reductions achieved in the power sector. Even with the current power sectors in most countries, BEVs have significantly lower "well-to-wheel" emissions than conventional vehicles. As renewable energy along with other power-sector innovations, the environmental benefits of BEVs likewise increase.

Despite the rapid recent growth in BEV sales and manufacturer's plans to produce more BEVs, there is a growing interest in the hydrogen fuel cell vehicle (HFCV) since it could offer a refueling experience and driving range that is more similar to an ICE vehicle. It is too early to predict the competition between the BEV and HFCV especially since it will be several years before the hydrogen refueling infrastructure can evolve to support widespread purchases of HFCVs. Like electricity, hydrogen is an energy carrier that can be produced from low emission sources such as renewable or nuclear electricity or fossil fuels with carbon capture storage and utilization.

Highlights on Power Market

Challenges and strategies surrounding the transformation of power sector are going hand in hand with increasing electrification and digitalization. As the role of electricity increases in final consumption in every corner of the world, the well-established traditional role of dispatchable generation is losing ground, leaving its place increasingly to variable renewables.

Governments around the world are under increasing pressure to provide clean, efficient and affordable electricity to their citizens. Power markets that are open with an efficient regulatory overview and a diversified energy mix are best able to provide energy supply security.

A wide range of technologies and new business models are developed and ambitious plans are put into action for a greater electricity infrastructure for the purpose of providing energy for all. Especially, innovations in mini-grids and off-grid renewable energy will continue to accelerate and facilitate easier electricity accession in rural places, especially those in Sub-Saharan Africa where the prevalence of energy poverty is greatest.

Green power technologies have become much more competitive in the recent decade. Onshore wind energy has become one of the least expensive sources of power in many regions that have good wind resources. Solar PV is now declining in cost along the same lines that onshore wind previously experienced. Renewable energy will continue change electricity generators' costs and generating capacities while demand management and other innovations will improve how power generation profiles are matched to load.

Since numerous factors have an effect on the cost of electricity generation, a common metric utilized towards measuring costs across fuels and technologies could be proven to be useful in decision-making process without diving further into complex calculations. Cost measuring metrics, such as Levelized Costs of Electricity (LCOE) and Levelized Avoided Cost of Electricity (LACE), despite their limitations, can still be benefitted in choosing an economically competitive project. Additional measures such as the value-adjusted cost of electricity (VALCOE) give utility planners and governments better tools with which to optimize power systems.

Electricity restructuring has been evolving since the 1990's. Transforming the energy industry by strong rules of competition towards higher efficiency and lower cost for consumers is necessary. However, if the motivation for restructuring simply focuses on 'rent shifting'; a new disruption in the power market would be inevitable and could increase vulnerability towards new shocks. Making electricity markets "more competitive" can mean many things. However, few liberalized electricity systems operate without the strong influence of government policies. These include regulations, feed-in-tariffs and other mechanisms. These aim to ensure adequate investments in electric generating capacity, supply security, environmental performance and access to electricity.

Highlights on CCS and GHG Policies and Integrated GHG Technology Scenarios

Carbon capture, utilization and storage (CCUS) has been included in many government's greenhouse gas mitigation strategies as it offers a way to reduce carbon emissions while continuing to benefit from their fossil fuel resources. While CCUS is likely needed to avoid the most severe impacts of climate change, especially considering large countries that rely on coal, and the growing role of natural gas in the power sector, carbon capture has achieved very little progress in the worldwide power sector.

While Turkey is not a large emitter, and it is adding considerable renewable energy to its generating capacity, Turkey could use CCUS to further reduce emissions while continuing to use its domestic coal resources. A paper assessing these opportunities for Turkey is included in this section. Nonetheless, the global status of carbon capture technology is not encouraging. The global uptake in the power sector is mostly limited to a few demonstration projects. For natural gas-fired power, CCUS is even more expensive per ton removed than for coal plants due to low flue gas pressure and other reasons. However, gas-fired electricity is expected to grow more than coal. Using CCUS with gas may be prove to be necessary to meet global climate goals. One-way to achieve lower cost CCUS with natural gas is to employ solid oxide fuel cells since they would have very low carbon capture costs compared to gas turbines. For this to be practical, grid scale solid oxide fuel cells (SOFCs) need to become more cost competitive and more reliable before they would be selected instead of natural gas turbines. A paper is included that discusses CCUS and SOFCs. A second included paper discusses carbon capture from natural gas using a completely different approach: chemical looping. This innovative approach also offers potential cost savings compared to flue gas removal.

There are several reasons why carbon capture has achieved relatively little commercial application in the power sector. CC barriers not only include high cost but a lack of cost engineering and basic equipment data making realistic assessments of the future of CCS quite difficult. The necessary conditions required for wider deployment of CCS have not occurred due to a lack of a supportive policy framework in the countries that could most benefit from CCS. Besides lacking a comprehensive regulatory environment, adequate storage assessments are not available. Another emerging problem, that is not often discussed, concerns power-sector market reforms and the increasing share of renewable energy. When electricity is priced as a minute-by-minute commodity, and there are more variable

renewables feeding the grid, thermal power producers need to adopt to a more flexible load-following power operation. However, CCUS technology and economics rely on a steady production of carbon dioxide to maintain transport pressures. If the capacity factors of baseload power plants become more variable (capacity payments are often used to maintain the operation of such plants), they become poorer candidates for the application of CCUS technologies.

Highlights on Regional Economies

For the last forty years, Turkey's energy policy has come a long way. The deployment of nuclear power plants, increased renewable utilization, the new gas pipelines and FSRU's along with the strong backing of up to regulations are some of the examples of achievements. These achievements, however; do not necessarily mean that there is no further need for improvement. Energy inefficiency, market liberalization and privatization, as well as inadequacy in grid integrations still need to improve for an optimized and efficient market structure. Cost-based energy pricing will also be needed. Cost-based pricing provides a more economically attractive and predictable energy market that is needed for adequate private-sector investment. The important role of government does not diminish in this scenario but adjusts to secure social welfare and ensure that Turkey's current "three pillars" of energy policy are secured: security of supply, localization, and predictability in the markets.

As one of the fastest growing power markets, India struggles to meet increasing energy demand, driven mainly by economic growth and population. Towards meeting this demand, India has put numerous policy agenda into action ranging from traditional sources to renewables. Among many alternatives, India has proven that the country has latent comparative advantages in solar energy. Manufacturing downstream products have been particularly more successful in comparison with in upstream segments of the solar PV value chain to which India needs to pay more attention. However, prospects are currently not good that India's renewable energy potential will significantly offset its likely large increases in greenhouse gas emissions as it continues to build coal power plants and exploit domestic coal resources.

After the promotion of the Vision 2030, Saudi Arabia has taken number of steps in order to meet its ambitious economic program. To reinvigorate the domestic economy and to balance the budget, reducing energy subsidies are a first step with a gradual decline each year. After the domestic economy was hit hard in 2014 with the decline of oil prices, the effort for economic overhauling has gained speed and consequently, energy prices for the domestic consumption have increased. This increase, however; has been carried out carefully to avoid hurting households' welfares. Nonetheless, fuel prices are expected to further rise gradually in the coming years with the aim of creating a better competitive environment.

Poland is considered as one of the most energy inefficient countries within the EU. Poland aims at increasing the share of renewable energy in its energy mix and modernizing infrastructures and inefficient coal fired power plants. The establishment of independent system operator for natural gas, opening up new LNG terminals and efforts in establishing more liberalized energy markets are some of the achievements appreciated within the EU.

Hungary has made a major stride forward in recent years by reducing carbon emissions, increasing the share of renewables and establishing day ahead electricity market with the neighboring counties. Nevertheless, various policy changes are still needed to achieve the goals set in the government's policy agenda. Energy efficiency, competitive power sector, market liberalization are some of the areas in which Hungary needs to take strict measures.

Becoming a natural gas hub has been at the top of the policy agenda for Greece in recent years with multiple gas pipeline projects. Greece holds the second highest share of solar PV in the EU and through a gas release program there

has been a significant progress made in the market liberalization. The fact that share of renewable and natural gas account for majority of power generation capacity, Greece holds a big potential in reducing the carbon emissions. Regarding the energy efficiency measure and the creation of competitive and financially viable markets, there is room for improvement for Greece.

Recently introduced energy reforms by the Mexican government have intended to open up the country's energy sector for both local and international investors. These sequence of reforms are expected to strengthen Mexico's international standing in international energy market, in particular, in energy trade. For the success of the reform, the pace as well as implications of the reforms are closely watched by the Mexican government.

Highlights on Innovations

Technological breakthroughs and innovations are unlocking many of the untapped potentials that have never been utilized in many sectors. The epicenter of the change in the coming years and decades will be inextricably linked to technological innovations and specifically to digitalization.

Digitalization is reaching more sectors than ever before with the promise of advancing safety, productivity and efficiency of the world energy systems. Nonetheless, digitalization comes with a risk of cyber-attack, economic disruption and privacy breach.

Increasingly digitalized energy systems hold a massive potential in changing the way how energy systems work. Through digitized energy systems, energy delivery will be timely, reaching at an exact location where it is most needed at a lowest cost possible.

The biggest impact of digitalization is expected in road vehicles with automation and better connectivity. Digitalization can also be utilized in oil and gas, in coal and power sectors. Demand increase in the power sector forces many governments to seek alternative solutions, innovative solutions
-such as digitalized utilities- have come at the right time, providing resiliency and greater control and agility to the pressing issues.

Highlights on Nuclear Energy

In recent years there has been a growing recognition that nuclear power may be needed to achieve global climate goals. Despite several economically troubled reactor builds in the OECD, the interest and investment in nuclear power is gaining especially outside the OECD. Nuclear is a dispatchable low carbon technology with other benefits such as no air pollution, supply security, grid stability and low land requirements. Consequently, nuclear energy has become important, especially for countries concerned about their energy supply security.

Nonetheless, nuclear safety remains a concern. The Fukishima Daiichi nuclear accident has further weakened trust in nuclear energy causing countries with successful nuclear programs to limit further development or close plants before their economic life. Public attitude towards nuclear energy have affected nuclear energy's growth from the very beginning of the industry, but especially after the Three-Mile Island accident in 1977 and, about a decade later, the much more consequential Chernobyl disaster. Nonetheless, nuclear power can be safe and reliable. Modern GEN III+ designs have better safety features than past reactors. Despite improved reactor safety, a culture of safety is required in the construction and operation of nuclear plants. A culture of safety means attention to and providing an absolute priority for safety. Achieving a safety culture is especially important for the "newcomer" nuclear power plant countries. An independent regulatory authority is required to oversee the country's nuclear industry and plant managers must exercise "bottom-up" attention to safety by well-trained plant workers in every aspect of nuclear power operation.

The major impediment with nuclear power has been that capital costs of building new power plants are still too high, which has significantly constrained the growth of nuclear power. Additionally, main developments that took place in recent years have further narrowed down the potential expansion of nuclear energy. Sluggish growth in electricity demand, and secondly, cost reduction in variable renewable electricity generation decelerated the expansion capacity of nuclear energy. Nevertheless, nuclear power expansion outside of the OECD is expected.

The best chances for a resurgence of nuclear power in the OECD, and around the world, may be the Small Modular Reactor (SMR). Being a manufactured turn-key product, the investment risks assumed by power companies are vastly reduced compared to constructing conventional on-site reactors. Unit sizes are much lower (50 to 300 MW designs are emerging). These “smaller chunks” of nuclear power better suit many countries’ power needs. Also, the reactors, being smaller, generally have greater passive safety due to features such as natural convection cooling. Several companies are developing designs in different countries. Multiple SMR designs are about to enter the certification processes of the nuclear regulatory agencies. We should soon see whether a commercial SMR industry will emerge, possibly as early as 2025.