Statement of
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Before
The Senate Environment and Public Works
Subcommittee on Clean Air and Nuclear Safety

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Good morning Chairman Braun and members of the Subcommittee. I am Bill Magwood, Director-General of the Nuclear Energy Agency. Thank you for the opportunity to appear before you today to provide my perspectives on the future outlook for nuclear energy.

The Nuclear Energy Agency is an intergovernmental agency operating within the framework of the Organization for Economic Cooperation and Development, the OECD. As you may know, the United States helped found the OECD as part of the Marshall Plan to prevent future wars, giving countries a common purpose to improve their citizens' living standards. The OECD—which is seen as an American success story—creates opportunities for U.S. businesses and workers throughout the world, and helps U.S. policymakers compare, evaluate, and understand the best options for both domestic and international policies.

Today's OECD helps save billions of dollars for American taxpayers and boosts the economic outlook for American businesses and workers. The U.S. has benefited from OECD work to combat international tax evasion, and currently the OECD is assisting the U.S. and other countries in developing a common approach to taxing the digital economy. The OECD is also helping to make the U.S. Foreign Corrupt Practices Act the gold standard around the world through the OECD Anti-Bribery Convention (see more about the OECD's activities in Appendix A).

The 33 members of the NEA are those countries with the deepest experience in nuclear technology, policy, and regulation. Our purpose for more than 60 years has been to facilitate cooperation among our members to address challenging issues associated with the use of civilian nuclear technology. We bring together the world's best expertise to establish common understandings about technical and policy matters and to find solutions in areas such as nuclear safety, radiological protection, nuclear waste, nuclear technology and economics, nuclear science, and nuclear law.

The United States is our largest member country and each year, dozens of Americans lead and participate in the many cooperative meetings, research projects, and working parties underway within the context of the NEA. We work very closely with senior officials and experts from the Nuclear Regulatory Commission, the Environmental Protection Agency, the Department of Energy, and the Department of State, as well as many U.S. experts from industry, academia, and national laboratories.

As the first American to lead the NEA since the 1980s, it is my pleasure to share observations based on the work of the Agency, it's expert staff, and the invaluable contributions of our members.

As I engage with leaders around the world, I find that in essentially every country with which we work, the level of uncertainty regarding the future of energy is currently at a very high level—perhaps the highest it has been since the oil shocks of the 1970s. In some ways, the uncertainty is even higher than that tumultuous period because we are today faced with radical shifts in technology, policy, and politics that make the picture of the future murky and unreliable.

This is particularly true in the case of nuclear energy. Just as many countries around the world seek to reduce emissions into the environment, nuclear energy in the developed countries of the OECD—including the United States—is on a declining path. Existing plants are faced with premature closure and few new plants are being built.

We have analyzed the reasons for these trends and they are varied and complex. Some countries have made political decisions to eschew nuclear or to emphasize other energy options at the expense of nuclear energy. Some countries face public resistance and concern about nuclear power plants in the aftermath of the Fukushima Daiichi accident. But the most important drivers for the declining prospects for nuclear energy in the U.S. and in many other OECD countries are economic.

First and foremost, the electricity markets have become dysfunctional in many markets around the world. It is not unusual to see market prices for electricity at zero or even negative during parts of the day. In many countries, the power companies that have provided reliable supplies of electricity face shrinking revenues just as the need for new investment is at its highest. I have had the leaders of power companies in several countries indicate to me that the only capacity they can afford to build is that which is subsidized by governments. These are no longer "markets" in any real sense.

Governmental interventions—including out-of-market subsidies and required shares for variable renewable energy—have contributed to these developments. However these conditions developed, they make the economics of operating a nuclear power plant very challenging. With zero marginal cost, variable renewables remove the floor in market prices, requiring baseload plants to either idle or operate at a loss during critical periods. Add historically low prices for natural gas in many places and the top of the market is compressed as well. As a result, nuclear plants are closing.

Overall, we believe that the electricity markets require significant reform. Around the world, whatever goals countries have for the future, today's markets are not serving their objectives. Markets should be balanced to provide for year-round reliability and stability and to enable electricity suppliers to make the investments needed to meet society's energy security and environmental goals. For those who are concerned about the emissions of carbon, the trends are particularly alarming. In the face of heavy investment in renewable energy sources, emissions are rising steeply and reached an all-time high last year.

We all certainly recognize the important and growing role of variable renewable energy in the world's long-term energy mix, and expect that wind, solar, geothermal, and other technologies will be essential in the transformation of the electricity sector over the next few decades. But the results thus far highlight the need for strategies that more accurately reflect the costs and attributes of renewables.

A report released by the NEA in January entitled "The Costs of Decarbonisation: System Costs with High Shares of Nuclear and Renewables"[1] demonstrates the vital role that variable renewables can play in the

[1] See the full report at https://www.oecd-nea.org/ndd/pubs/2019/7299-system-costs.pdf

future energy supply—but as part of a well-balanced portfolio (see additional information in Appendix B). In the case of very high shares of variable renewables, such as 75%, our work shows that the cost of providing electricity skyrockets—easily double what it could be because of the variable and unpredictable nature of renewable supply and the fact that, according to our work, total capacity would need to triple in size if the share of renewables were to reach very high levels. Such a system would also be faced with considerable inefficiencies and many technical challenges.

The contribution of renewables should reflect the realities of the electricity system in which they are to be deployed and the cost of the renewable resources available. Each country should assess the full costs of all its potential sources of supply and develop the balance of renewable and baseload supplies that best fits its particular circumstances. The balance is likely to be different from country to country. As it becomes clear that the amount of baseload supply needed in the future is not zero, each country will need to decide how it will meet its future electricity supply needs.

This would certainly appear to create an important opportunity for nuclear energy. Nuclear energy is the only expandable, dispatchable source of large-scale electricity that does not generate air emissions. Countries around the world have benefitted from the reliability and price stability provided by nuclear power plants for more than fifty years. Yet, nuclear energy is on path to decline in North America, Europe, and OECD Asia.

Today, few plants are under construction in OECD countries. As reflected by the projects underway in the United States, France, Finland, and Slovakia, the nuclear industry in most OECD countries has a damaged reputation as a reliable supplier of plant and equipment. Eye-watering cost overruns, schedules for completion missed by a decade, failed projects, and stratospheric cost estimates for new builds do not build confidence.

The fact is that the capacity to build nuclear power plants in the countries that led nuclear development in decades past has deteriorated. The skilled project leadership, supply chains for critical nuclear-quality components, and trained workforce needed for the effective construction of new nuclear plants simply have not been available to support nuclear projects in most OECD countries. After not building nuclear plants for decades, they are like the overweight man who never exercises but decides to clear his driveway of two feet of snow in a Washington winter. It's not a pretty sight.

Among OECD countries, only Korea has maintained a long-term building program that enables it to supply nuclear plants to cost and schedule requirements. In contrast, Russia and China are quite proficient in building plants and are currently the most aggressive countries in the international market for new plants. Both countries have benefitted from continuous build programs and have developed world-class construction expertise and robust supply chains. Organizations from these countries are winning contracts in both developing countries and in highly developed countries. Russia has proven its capabilities in Iran and Bangladesh and is now developing projects in Finland, Turkey and other countries. China has signed agreements to build in Argentina and is likely to construct a plant in the United Kingdom. In addition to their construction capabilities, both countries are offering financing for projects that can make the difference between an aspiration to build and a project to build.

The success of suppliers from Russia, China, and Korea demonstrates that the difficulties faced by projects in the US, France, Finland and elsewhere have less to do with the nature of nuclear projects and much more to do with the lack of proficient, experienced construction capacities in countries that haven't hosted continuous nuclear build programs since the 1980s.

Given the experiences of recent years, I don't believe you will find any CEOs of U.S. electric utilities who would consider building a nuclear plant today. The costs are too high, the risks are too high, and the uncertainties are too high. Some CEOs have told me that they believe we have seen the last large light water reactor to be built in the United States.

Many government and industry leaders hope to leap-frog these difficulties by shifting from light water-based Generation III nuclear designs to new technologies—small modular reactors that can be largely built in factories and Generation IV technologies that seek to shift old paradigms. Just last week, at the Clean Energy Ministerial held in Vancouver, governments and industry came together to discuss and pave the way for these new technologies. Most of the nuclear discussions were held in the context of the Nuclear Innovation: Clean Energy Future initiative—NICE Future—which was launched last year by the U.S., Canada, and Japan.

Gas-cooled reactors, liquid metal reactors, molten salt systems and others are being pursued. These are exciting technologies that offer many bright hopes. If successful, the potential exists for the introduction of technologies that have economic, flexibility, and safety characteristics that could entirely change the global discussion about energy.

Beyond even the shift in technology, discussions in Vancouver highlighted a shift in leadership in nuclear technology development from the government sector to the private sector. It is estimated that more than 30 companies are today developing advanced nuclear energy technologies—most of them Generation IV technologies. Many others are working on fusion energy as well.

This new, private sector-led approach to development is somewhat inspired by the success by NASA in encouraging innovation in space technology by supporting the private sector. Governments, particularly the U.S., Canada, United Kingdom, and Japan are emphasizing this approach and have moved away from the traditional government-led development model that led to past nuclear technology innovations.

This new approach, however, faces important questions. As we watch this transition from government to private sector leadership, I highlight three primary areas of concern that must be addressed if these initiatives are to be successful.

First, it is important to recognize the unique nature of nuclear technology development. The reason nuclear technology development has been led in the past by governmental organizations is because it is very technically challenging, expensive work that requires access to facilities that can manage safety and securely nuclear materials. As anticipated by DOE's Gateway for Accelerated Innovation in Nuclear (GAIN), national laboratories can support some of these needs.

This requires an approach to enable companies to benefit from the broad expertise and capabilities in national laboratories. This matter was discussed last week in a unique meeting sponsored by the Canadian government that brought together a dozen or so leaders from companies developing new nuclear technologies for market and the Generation IV International Forum (GIF). The GIF, which is facilitated by the NEA, has been active for nearly 20 years as a global framework for advanced reactor research cooperation between the world's leading countries in advanced research. It is led by government and national laboratory experts who have always worked in long-term government-sponsored research and development activities. The meeting demonstrated that the needs of the private sector are driven by investor impatience and the need to support regulatory processes. These imperatives contrasted with the long-term research approach of the government sector.

These discussions also highlighted that developing a new light water technology and shepherding it through regulatory approve is likely to cost at least $1.5 billion. Generation IV technologies are likely to cost substantially more. The typical company participating in the Vancouver meetings have perhaps a dozen engineers and scientists devoted to their technology development efforts and access to a few tens of millions.

In comparison, I recently visited the Shanghai Institute of Applied Physics, which is developing a molten salt reactor technology. Molten salt reactors are an area of high interest to several private sector companies—including TerraPower which is represented here today—because it represents both a path to extraordinarily safe and efficient nuclear reactors that consume nuclear waste rather than generate it. The project at SINAP currently has over 400 scientists and engineers hard at work developing the technology with plans to build a demonstration reactor within the next decade. In terms of resources, this project is larger than the combined resources of all the companies that participated in the Vancouver meetings.

I make this contrast to highlight that the private companies upon which OECD countries are largely relying will need access to orders of magnitude more resources to be successful. Investors will look for early indications of success and a clear opportunity to enter the market in the foreseeable future. How some of the 30-odd companies aspiring to bring Generation IV technologies to reality will acquire the resources and expertise necessary for success is not clear. Government-sponsored technology projects in China and Russia appear to have a clearer path to market.

The second challenge is related to an issue I mentioned earlier—the dysfunction in today's energy markets. Prices for electricity in the U.S. are very low, which is good for consumers, but it provides limited incentive to private investors to support new nuclear energy technologies. There are, fortunately, visionary investors who are willing—for the sake of future generations—to launch the exploration of new technologies. But billions will be needed. In contrast to NASA, which provided the market to incentivize private space efforts, the markets for energy today cannot sustain fully depreciated existing nuclear power plants. It is, therefore, challenging to make an economic case for massive private investment in unproven technologies.

A possible exception might be the case of "microreactors", which could be deployed for specific niche purposes—such as providing energy for remote communities, to support military deployments, or mining operations—but these face interesting regulatory questions regarding their deployment that remain to be resolved.

And this brings me to the last major challenge: regulation.

I will begin by stating that I am not particularly concerned about the ability of regulators, given sufficient lead time, to react to new technologies. Many observers call for more "streamlined" licensing to ease the introduction of advanced technologies, but I believe that the current frameworks in the U.S. and most other nuclear safety regulatory agencies can be adapted to license new technologies.

Clearly, more can be done to make the process simpler, but I don't believe radical changes are necessary to move technologies forward. The NRC is considering how to modernize its framework and adapt it to non-light water reactor technologies, but even without these analyses, work conducted in the course of DOE's effort to develop the Next Generation Nuclear Plant a decade ago demonstrated that the existing regulatory tools available to the NRC would allow for the licensing of an advanced technology.

Rather than a matter of framework and regulation, the most significant challenge for regulators will be to adjust the mindset of their staffs toward new concepts and technologies. They must be more willing to

become partners in innovation, though without violating their independence as nuclear safety regulators. Each regulator will need to manage its way to the appropriate balance.

The private sector has also expressed interest in having the NRC develop a step-wise approach to licensing new technologies along the lines of the pre-licensing vendor design reviews (VDRs) that can be conducted by the Canadian Nuclear Safety Commission (CNSC). This type of approach is helpful to small companies looking for ways of communicating progress to potential investors.

Nevertheless, at the end of the day, there is no short-cut to licensing advanced nuclear reactor technologies; nor should there be. The process will be expensive, time-consuming, and likely require testing that can best be completed in established nuclear complexes such as national laboratories. No matter how regulators approach the licensing, the information they will need to make licensing decisions will be similar around the world.

This will require greater international coordination in the use and sharing of research facilities around the world. The NEA is today working with our members to address gaps in the global framework for the testing of new nuclear fuels and materials. This experience will be invaluable as regulators seek technical information regarding advanced reactor systems.

In my view, the bigger challenge for regulators will be to find ways to avoid forcing companies to resolve technical and regulatory questions about new technologies multiple times as they seek to introduce their technologies in multiple countries. Today, obtaining regulatory approval for a technology in Korea or France means very little if you wish to build the technology in the United States. For light water technologies, it requires about four years and the order of half a billion dollars to navigate approval processes. It is extraordinarily costly and inefficient if this must be done in each country for each technology.

Moreover, if regulators can reach common positions on key aspects of technologies—such as requirements for autonomous operation and the nature of emergency preparedness requirements—companies can provide their products around the world applying the same rules. For small reactors in particular, which would benefit most from access to the largest practical market, this is a vital issue. We at the NEA are exploring how this issue might be resolved.

Conclusion

The need for nuclear energy technology is clear, but the path in the U.S. and other OECD countries to develop and deploy these technologies is not. The only major Generation IV nuclear technology demonstration projects underway today are in China, Russia, and India. These countries have implemented and continue to implement advanced reactor demonstrations across a broad front. Russia's BN-800 sodium-cooled fast reactor and floating nuclear power plant and China's high temperature gas-cooled pebble-bed modular reactor are examples of successful projects and more are on the way.

The traditional nuclear development countries have not implemented a successful Generation IV reactor technology program since the 1980s and the expertise and infrastructure these countries built over the decades have eroded dramatically.

The U.S. and many other OECD countries rest their hopes on a large number of mostly small innovation companies that aspire to develop game-changing technologies for the future. But to be successful, these companies will need a supportive market, access to significant expertise and resources, and regulators who are prepared to support innovation and the development of a global market.

Appendix A: Additional Background on the OECD

The United States helped found the Organization for Economic Co-operation and Development (OECD) as a bulwark against further wars, giving countries a common purpose to improve their citizens' living standards and quality of life. Today, the OECD has updated its mission to help countries design and deliver "Better Policies for Better Lives". The OECD's work creates opportunities for U.S. businesses and workers throughout the world and helps U.S. policymakers compare, evaluate, and understand the best domestic policy options for their constituents. Today's OECD helps save billions of dollars for American taxpayers and boosts the economic outlook for American businesses and workers. Here are just a few of the ways the OECD makes a difference and adds value for the U.S.

THE OECD: REAL RESULTS FOR THE UNITED STATES

Levelling the Playing Field for U.S. Businesses, Saving Money for U.S. Taxpayers

- The OECD's Export Credit Agreement **saves American taxpayers over $800 million per year**. It prevents countries from distorting international markets through subsidized export credits or tied aid. This reduced costs and **allowed U.S. firms to increase their exports by billions annually**. Taxpayer savings result from guidelines on interest rates and risk premiums charged for export financing, and from rules on the use of donor aid.
- The U.S. has also benefited from OECD work to **combat international tax evasion and promote transparency**. Close to $85 billion has been collected through voluntary disclosure and similar initiatives in advance of the first exchanges under the OECD's Common Reporting Standard, which was endorsed by the G20 and more than 100 jurisdictions. **Almost $10 billion of this additional, unplanned revenue has been collected in the U.S. alone.** To enable countries to implement the Standard in a consistent and cost-effective way, the U.S. and other members asked the OECD to procure a Common Transmission System – the IT infrastructure to undertake the bilateral exchanges of tax information. The OECD has also provided a platform for tax cooperation, which is the best way to protect and enhance countries' sovereignties while providing more certainty to business. The OECD/G20 BEPS project has facilitated a revision of **transfer pricing guidelines** and the **model tax treaty** which underpin over 3700 bilateral arrangements. The U.S. has inspired these rules, which are now endorsed by all OECD and G20 countries.
- Commitments made by OECD members under the **OECD Codes of Liberalization of Capital Movements**, have resulted in opening their markets to U.S companies. In the process of adhering to the Codes, new European countries have extended to US companies the liberalization benefits of EU common markets in a range of industries, from financial services to films. Commitments under the Codes to refrain from using capital controls also contributed to discouraging exchange rate management aimed at gaining unfair trade advantages.
- More than $1 trillion in bribes are paid worldwide each year, which some experts estimate to be equivalent to a 20% tax on foreign investment by U.S. and other countries' firms. The OECD **is helping to make the U.S. Foreign Corrupt Practices Act the gold standard around the world through the OECD Anti-Bribery Convention**. U.S. peer pressure on other Parties through the Convention's monitoring process is paying off. For example, in a recent case the authorities in Brazil and Switzerland joined those in the U.S. to successfully prosecute a Brazilian company for foreign bribery, resulting in the largest global fine ever – USD 3.5 billion.
- Through the **OECD Due Diligence Guidance for Responsible Supply Chains of Minerals from Conflict-Affected and High-Risk Areas** the OECD is leveling the global playing field for U.S.

companies. The EU and others have followed the US example and recognized OECD guidance on due diligence in their laws and regulations.

- The services sector generates 80% of American jobs and 75% of U.S. economic output. The OECD Services Trade Restrictiveness Index (STRI) **helps the U.S. government and business community to identify trade barriers and regulatory obstacles in both the US itself, as well as in foreign markets** on a sector-by-sector basis.
- The OECD Guidelines for the Testing of Chemicals and Good Laboratory Practices **save member governments and industry approximately $165 million annually – a significant portion of which accrues to the U.S. government and chemical industry**.
- The OECD is also working to **eliminate unfair competition that can hurt U.S. companies abroad**. Working with governments around the world, the OECD is helping clarify the nature and role of state-owned enterprises and how they may shape trade. Likewise, the OECD Declaration on International Investment and Multinational Enterprises and the OECD Guidelines for MNEs provide certainty to investors as the most comprehensive set of recommendations on responsible business conduct in existence.
- As American firms compete in global value chains, OECD measurements on trade in value-added (TiVA) provides American policymakers with **evidence to make smarter choices on trade policy and the best new markets** for U.S. firms, both export destinations as well as sources for intermediate inputs.
- **The U.S. — the world's 4th largest steel producer — suffers significantly from global excess capacity.** The OECD facilitates the **Global Forum on Steel Excess Capacity in the context of the G20** to address industry reform. **The U.S. has been a founding member and key partner of the OECD Steel Committee** since 1978.

Supporting Stronger Domestic Policies for America's Future

- The OECD is a **go-to resource for American policymakers** and the public to identify information and strategies to build better policies. **The Congressional Research Service has cited OECD facts and figures in its reports to Congress more than 1,500 times since 2003**.
- The U.S. spends more than $600 billion on public K-12 education annually. The OECD's Program of International Student Assessment (PISA) **helps to measure return on education investment** – specifically, how American 15-year-olds perform in reading and math and science. The Program for the International Assessment of Adult Competencies (PIAAC) measures proficiency in numeracy, literacy and problem-solving in technology-rich environments.
- The U.S. spends nearly $20 billion each year to help put Americans back to work. The Job Creation and Local Economic Development report **identifies U.S. regions with the strongest job-creation prospects**. The Skills Strategy and the OECD's work on displaced workers suggest **cost-effective improvements to provide job training and opportunities for all**.
- Small businesses are the backbone of the U.S. economy, accounting for 99.7% of all employer firms and nearly half of private-sector employment. OECD data **help the U.S. do better by small businesses,** monitoring financing needs and gaps and exploring policy options to **get SMEs the funds they need.**
- The OECD has contributed to the debate on domestic **tax reform** (2016 U.S. Economic Survey, 2016 Revenue Statistics) with **proposals to address the high corporate tax rate**. The U.S. business

community has made a strong contribution to the 2016 OECD survey on the sources of tax uncertainty, which will help countries develop a tax system that promotes investment, trade and balanced growth.

- Knowledge-based capital (KBC) accounts for more than half of U.S. business investment. OECD research has **proven the benefits of innovation-driven business models**. Under U.S. leadership, we have adopted the OECD Principles for Internet Policy Making.
- U.S. health spending per capita is higher than that of other OECD members. The OECD compares detailed health spending data across countries and identifies ways **to do more and better with less.**

A Partner for the U.S.

The OECD is doing all this work with a **decreasing share of U.S. contributions**. Thanks to financial reforms, America's share of contributions to the OECD core budget has **fallen from 25% to 20.6%** in the last decade. According to the Department of State, the U.S. paid over $104 million in 2008 to the OECD via the Contributions to International Organizations account. In 2017, the contribution to the OECD was $70 million. The OECD work program and budget are managed through best standards, applying results-based management to provide U.S. tax payers with the **highest possible value for money**. Looking to the future, the share of **U.S. contribution to the core budget is expected to continue decreasing to 18.2%** within 10 years, potentially less if new countries join the organization.

Appendix B: The System Costs of Electricity

THE SYSTEM COSTS OF ELECTRICITY REFLECT THE TRUE COSTS OF DECARBONISATION

- Limiting the rise of global temperature to less than 2°C represents an enormous challenge for the whole electricity sector.
- Decarbonising the electricity sector in a cost-effective manner while maintaining security of supply requires the rapid deployment of *all* available low-carbon technologies.
- Today's electricity markets make investment in any unsubsidised low-carbon technology economically impractical.
- System costs are the result of inefficiencies imposed on the entire electricity system due to the increased share of variable generation.

What's the issue?

The future is electric. Decarbonising the energy sectors and the economies of OECD countries will require electrification of not just the transportation sector, but also industry and buildings. Effective action to reduce carbon emissions and to limit climate change depends on the creation of a robust low-carbon electricity sector.

Reducing the carbon intensity of the electric power sector to 50 gCO_2 per kWh (which would be necessary to meet Paris Agreement goals) is a major challenge. This level is one-eighth of the current levels and requires a rapid and radical transformation of the power system with the deployment of low-carbon emitting technologies such as nuclear, hydroelectricity and variable renewable energy (VRE). This will mean phasing out coal and strictly limiting the use of gas-fired power generation.

This change must be approached carefully and with a full understanding of costs and impacts of various technologies. For example, increasing the share of variable renewable energy (VRE) results in large inefficiencies in the entire electricity system.

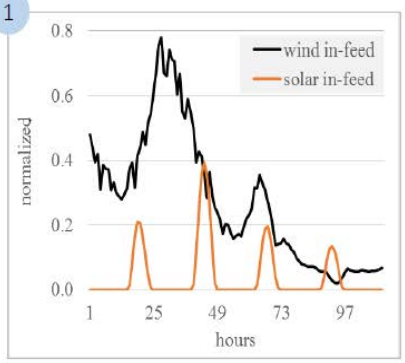
These issues appear as overall system costs, caused mainly by the intrinsic characteristics of variable generation, are currently not correctly allocated to the generation sources that cause them. They also result in significant challenges for the management of the electric system, and volatile and unpredictable electricity prices.

In part because of these effects, the existing electricity market structures make investment in any unsubsidised low-carbon technology economically impractical.

Given the massive investments that the realisation of the decarbonisation transformation requires, it is of paramount importance to create long-term frameworks that provide stability and confidence for investors in all low carbon generation technologies. It is also imperative to realign electricity systems and electricity markets to ensure security of supply and system reliability in a cost effective manner.

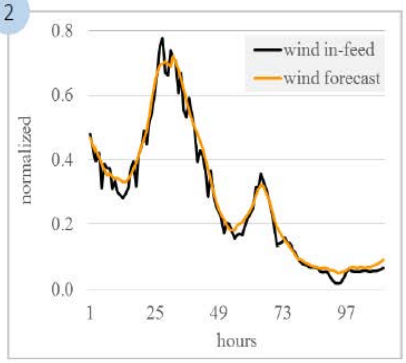
System costs are mainly due to characteristics intrinsic to variable generation

1



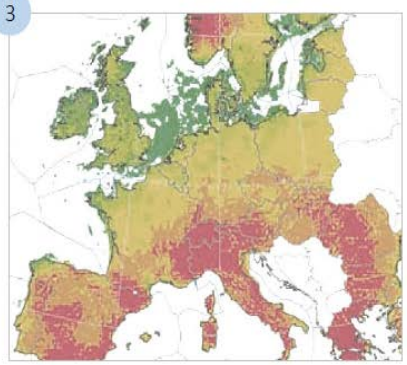
VREs are not always available

2



VREs are difficult to predict

3



Good VRE sites are distant from load centres

What should policy makers do?

Radically decarbonising the electricity sector to 50 gCO_2/kWh in a cost-effective manner while maintaining high levels of security of supply therefore requires five complementary policy measures:

Recognise and fairly allocate the system costs to the technologies that cause them: Carbon pricing will recognise the environmental attributes of low-carbon generation, while capacity remuneration could recognise dispatchability. Exposure to electricity prices would internalise profile costs, and remunerate each unit of electricity generated at its true value for the system.

Foster truly competitive short-term markets for the cost-efficient dispatch of resources. Marginal cost pricing based on short-term variable costs is the appropriate mechanism to ensure the optimal utilisation of existing resources, i.e. to produce a MWh of electricity at the lowest possible costs at any given moment and to expose generators to the discipline of market prices.

Encourage new investment in all low-carbon technologies by providing stability for investors: In creating sustainable low-carbon electricity systems, all low-carbon technologies will need to play a part. However, their high capital intensity requires specific financing solutions as they will not be deployed solely on the basis of marginal cost pricing in competitive markets. This holds for all low-carbon technologies. This is why policy makers have to make tough calls on striking the appropriate balance between out-of-market support and exposure to wholesale market prices for low-carbon technologies with high fixed costs such as nuclear and VRE. Feed-in tariffs (FITs), long-term power purchase agreements (PPAs), contracts for difference (CFDs), regulated electricity tariffs, feed-in premiums (FIPs) or even direct capital subsidies through, for instance, loan guarantees, are all appropriate instruments to achieve long-term security of supply with low-carbon technologies.

Enable adequate levels of capacity and flexibility, as well as transmission and distribution infrastructure: generation is at the heart of any electricity system, but the electricity system requires frameworks for the provision of capacity, flexibility, system services and adequate physical infrastructures for transmission, distribution and interconnections. The variability of VREs and new technological developments make these complementary services increasingly important. It is also important to recognise the positive contribution to system stability and inertia of large centralised units such as nuclear power plants or hydroelectric dams and to value them appropriately.

Implement carbon pricing, as the most efficient approach for decarbonising the electricity supply: This approach would increase the cost of high-carbon generation technologies, reduce greenhouse gases and enhance the competitiveness of low-carbon technologies such as nuclear and VRE. Carbon pricing will produce an overall gain for society. However, it will also produce losses for some stakeholders, in particular, fossil fuel producers and their customers. Appropriate policies to facilitate a "fair transition" for the affected businesses and households, and particularly those in vulnerable regions and communities will be needed. No one can be left behind.

Why is this important?

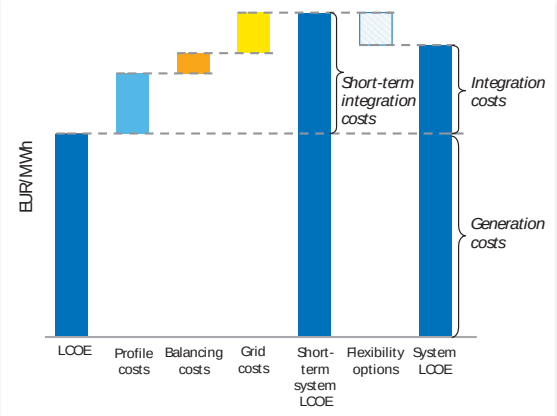
The ultimate objective of policy-making in this area is the decarbonisation of the electricity markets. Current projections are that this goal would require a 73% reduction in the world's total annual CO_2 emissions from electricity generation and an even more ambitious 85% reduction of the annual emissions in OECD countries. Ambitious decarbonisation targets require the optimum use of all available low-carbon technologies, but current electricity markets are not enabling the reduction in carbon intensity necessary to meet the Paris Agreement goals.

Projections in the new NEA study reveal that the true costs of decarbonisation are not being reflected in today's electricity markets. For example, increased share of variable renewable energy (VRE) results in large inefficiencies in the entire electricity system. One of these inefficiencies manifests as the vast excess capacity that is needed to meet the demand. For example, if a system were to go from 0% to 50% VRE penetration, installed capacity would need to double to meet the same demand.

At the same time system costs significantly increase. For example, under the same scenario (increase from 0% to 50% VRE penetration), system costs would make up 35% of total costs to meet the same demand.

Finally, existing electricity frameworks lack signals that encourage long-term planning and investment in low carbon technologies to ensure security of supply and system robustness.

Illustration of system costs



Source: OECD (2015), *Projected Costs of Generating Electricity: 2015 Edition*, IEA and NEA joint publication, OECD, Paris.

Who is working on this?

This study was prepared by the Nuclear Energy Agency, a specialised agency inside the Organisation for Economic Co-operation and Development family. For many years the NEA has analysed different aspects of the costs of electricity. This work focuses on all sources of power generation, examining the plant-level costs, system costs and security of supply. NEA's goal is to enable policy makers and the public to take better-informed decisions along the path towards fully sustainable electricity systems