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White Paper

Accelerating Sustainable Energy Innovation

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Contents

Foreword

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Sustainable energy innovation is at the heart of solving many of the world's toughest challenges, and is the key to tapping the full potential of energy as a contributor to future growth and prosperity.

However, despite the overall accelerating pace in recent years, innovation in the energy system is not occurring quickly and widely enough, nor is it adequately aligned, to address pressing issues and exploit new technologies to improve the lives of citizens around the world. The global energy system faces rising and shifting demands: the urgent challenge of tackling climate change and the need to expand energy access, mirrored by tremendous new opportunities created by the Fourth Industrial Revolution, which affect all sectors of the economy and society.

In this context, the World Economic Forum's *System Initiative on Shaping the Future of Energy* aims to accelerate development of the policies, private-sector actions and public-private collaboration required to achieve a sustainable, affordable, secure and inclusive energy future essential for economic and social development. *Partnering to Accelerate Sustainable Energy Innovation* is a project initiated within this system initiative*,* following the World Economic Forum Annual Meeting 2017 in Davos.

The project's goal is to identify and promote actions that the global community can take to accelerate the pace of innovation in sustainable energy and, in parallel, serve as a platform for collaboration among stakeholders from business, government, civil society and selected innovation alliances who share a vision for a sustainable future. From this platform rose the collaboration between the World Economic Forum and Mission Innovation, an alliance of 22 governments and the EU representing 80% of global clean energy research, development and demonstration (RD&D), who joined forces to accelerate sustainable energy innovation.

Energy innovation systems need a stronger and more effective push to deliver a broader range of technologies and solutions to market faster than what is available today. The importance of accelerating innovation in sustainable energy – across the many ways in which energy is produced, delivered and consumed – is undervalued by many, and underinvested compared to the challenges at hand, but this can be changed.

The World Economic Forum and KPMG, partner for the project, are pleased to share preliminary insights gathered from World Economic Forum constituents from more than 30 structured interviews with diverse groups of experts, as well as from literature reviews, a comprehensive research of existing energy innovation projects, collaboration with Mission Innovation, and a series of multistakeholder dialogues in Europe, Asia, North America and Latin America. In this interim report, we identify the need for a systemic approach and the global catalysts and actions that can reinforce innovation across various stages and technologies. We also offer a few "bold ideas" with potential to create bigger step-changes, designed to inspire decision-makers and spark discussion.

We would like to thank the advisory board for *Partnering to Accelerate Sustainable Energy Innovation* and the many other experts and stakeholders who have contributed greatly to the project and to this white paper. We are on the verge of global energy transformation, and we look forward to continuing the work that is so central to the future of energy and its impact on global prosperity.

1. Executive summary

Energy consumption and production activities contribute two-thirds of global greenhouse gas (GHG) emissions. As such, energy also has the greatest potential to help slow GHG-driven climate change, by accelerating the pace of innovation and large-scale deployment of sustainable energy technologies.
According to the International Energy Agency, among 26 identified innovation areas, only solar PV and onshore wind, energy storage and electric vehicles are sufficiently mature and commercially competitive to conventional energy sources, and are on track to deliver their share of meeting climate objectives. However, the urgency of climate change requires a much wider toolkit of sustainable energy solutions to be mature enough for large-scale deployment.
The global energy transition to a low-carbon future requires accelerated innovation across multiple nascent sustainable energy technologies, and a systemic approach for their deployment at scale. This interim report from the World Economic Forum's initiative *Partnering to Accelerate Sustainable Energy Innovation* identifies the key enablers of the innovation process and proposes some ideas to achieve step-changes in the pace of sustainable energy innovation. The insights in this report have been gathered from Forum constituents in over 30 interviews with diverse groups of experts, literature reviews, collaboration with Mission Innovation, and a series of multistakeholder dialogues.

Despite the recent surge in investment in clean energy and the evolution of enabling policy instruments, investments in clean energy RD&D are too low and significant barriers to innovation remain.
Investment in clean energy RD&D is low and has been flat over the past few years. A real step-change in funding must involve both governments and the private sector. Through the Mission Innovation collaboration, 22 governments and the EU – already representing 80% of global government clean energy RD&D have pledged to double their investments by 2021. Yet, public investment in sustainable energy RD&D can benefit from improved effectiveness, and there are few incentives for companies to invest in-house on research activities. High risk, low return and a long lead time to maturity in deep-tech energy solutions do not make them sufficiently attractive investment propositions for companies from the energy sector, nor for venture capitalists (VCs) and private equity firms. Fossil fuels continue to be subsidized in many countries across the globe, and the enforcement of carbon pricing and emission reduction mandates is, at best, patchy. Policies and other measures should also target investments to enable integration of new technologies in the existing energy infrastructure for their deployment at scale. Finally, the carbon-based sociotechnical system has created a behavioural and economic lock-in across different end-use categories, limiting the adoption of sustainable energy solutions.

The sustainable energy innovation challenge requires a systemic and multistakeholder approach to help bring a broader set of nascent technologies to technical and commercial maturity.
It includes variety of perspectives and disciplines, including innovation systems, transition studies, environmental and ecological economics and policies, and an enabling framework that aids productive interaction between system components. Energy transition is a complex process, which needs to balance the priorities of economic growth, energy security and system reliability along with environmental sustainability. This necessitates interdisciplinary perspective and collaboration between innovators, system planners, regulators, investors and end-use consumers. Governments and the private sector must improve complementary efforts and seize opportunities to cooperate in areas that can benefit from public-private collaboration and which neither governments nor businesses can solve on their own.

Regulatory policies, public-funding programmes and innovation alliances are key catalysts necessary to accelerate the pace of innovation.
More transparency on scalable and replicable good practices of policies, programmes and alliances will encourage innovation activity and large-scale integration of new technologies, solutions and business models in the energy system. Based on the review of positive examples from across different countries, the following are a few key success factors of the aforementioned catalysts:

– **Regulatory policies** create an enabling environment for innovators, investors and consumers to participate in the new energy economy. The regulatory framework should consider aligning several instruments that reinforce the positive effects in advancing innovation in sustainable energy, including incentives for early adopters, de-risking mechanisms for investors, and compelling rationale to end-consumers for accelerated adoption. Energy policies do not work in isolation, but interact closely with other policy areas, such as trade, investment, and industrial and infrastructure development. An effective policy regime with a credible agenda and long-term stability is crucial to accelerate innovation in sustainable energy.

– **Public funding programmes** provide much-needed early support to nascent technology areas in the form of RD&D subsidies, research infrastructure and interdisciplinary and multistakeholder collaboration. ARPA-E (USA), Kopernikus Program (Germany) and KIC InnoEnergy (EU) are some good examples of innovation programmes that use collaborative R&D processes, and a value-chain approach in engaging with innovators and entrepreneurs. Mostly sponsored and administered by government agencies, public funding programmes need to take a systemic approach in promoting innovation across the energy value chain and focus more on market deployment by creating opportunities for follow-on financing from the private sector. Moreover, long-term and mission programmes along the lines of the Japanese hydrogen programme and the Danish wind energy programme are more likely to offer systemic breakthroughs as well as a competitive edge to countries in specific technology areas. Although numbers on private-sector RD&D funding in sustainable energy are scarce, those that exist indicate the levels lag behind other sectors such as, for instance, IT, and there is a need for the private sector also to increase levels of RD&D funding to make more capital available to solve sustainable energy innovation challenges.

– **Innovation alliances** in the form of increased collaboration within and between public and private sectors are essential to ensure multistakeholder participation in sustainable energy innovation. Mission Innovation, Breakthrough Energy Ventures and Hydrogen Coalition represent high-profile partnerships that serve to advance innovation and the scaling-up of sustainable energy technologies. In order to be more effective, alliances for sustainable energy innovation need to be more focused on impact and should have a well-defined purpose and focus. There is a strong case for alliances to embrace a diverse membership across different industries and geographies, and to have access to key decision-makers in the public and private sectors in order to be more effective.

These catalysts serve to create an enabling environment to foster innovation. Specific actions, however, must result from collaboration among the people who form the core of the innovation process – the inventors, entrepreneurs, corporates, investors, policy-makers and consumers.

This report offers a few forward-looking bold ideas to achieve step-changes in the innovation process:

1. Use an institutional approach to energy innovation to better connect isolated groups of experts and plug the gaps that prevent faster conversion of basic research to commercially feasible projects, thus taking a longer-term view and avoiding problems of shorter political cycles.
2. Provide better support to capital-intensive innovation areas and encourage collaboration in the pre-competitive stages of innovation through an independent international fund that pools RD&D investment from countries, companies and philanthropists.
3. Develop instruments for co-investment of public RD&D grants with venture capitalists to better target grant recipients, lower administration requirements of grant applications, create collaborations between public and private capital sources and enable better timing of grant availability.
4. Co-design technology roadmaps across the public and private sector, and across borders, to improve credibility, speed up commercialization and bridge the technical and financial "valleys of death" that plague innovation.
5. Mainstream public procurement strategies for sustainable energy solutions, redesigning them to be forward-looking, to focus on outcomes rather than specific technologies, and to offer "demand-side assistance" to early-stage innovations in areas where technology solutions do not exist.
6. Improve transparency on public RD&D expenditure for sustainable energy innovation, employing existing multilateral frameworks such as Mission Innovation to facilitate better data sharing between countries, and identify and better address underserved innovation areas.

2. Climate change and the need to accelerate sustainable energy innovation

Energy is critical to solving the climate change challenge, but no quick fixes or silver bullets are in sight.

Energy is the backbone powering our economies and modern human activity with multiple benefits for society. Transportation, industry and households consume energy in the form of electricity or fuel, produced from different renewable and fossil fuel sources and delivered through an array of infrastructures built and operated by many actors.

At the same time, tackling the negative environmental effects of the global energy system has never been more pressing. Energy consumption and production is responsible for more than two-thirds (68% in 2014) of the world's greenhouse gas emissions. Also, energy consumption and production contribute a significant share of local air pollution. This has become a critical issue in many countries, adding further urgency to tackling the sustainability issues of energy while also ensuring energy is affordable, secure and available for all.

New projections indicate that, by the end of 2017, global emissions of carbon dioxide from fossil fuels and industry are projected to rise by around 2% compared with the preceding year, after remaining flat between 2014 and 2016. The challenge of reducing emissions is not to be underestimated (see Figure 1). Action is required on several fronts, from scaling clean-energy technologies and energy-efficiency solutions that are market-ready immediately, to accelerating the process of innovation and bringing a much broader range of new technologies and solutions to market as soon as possible. Indeed, nothing short of an innovation tsunami is required to achieve a 2°C rate of global warming or lower.

A few positive developments are unfolding, but progress is slow.

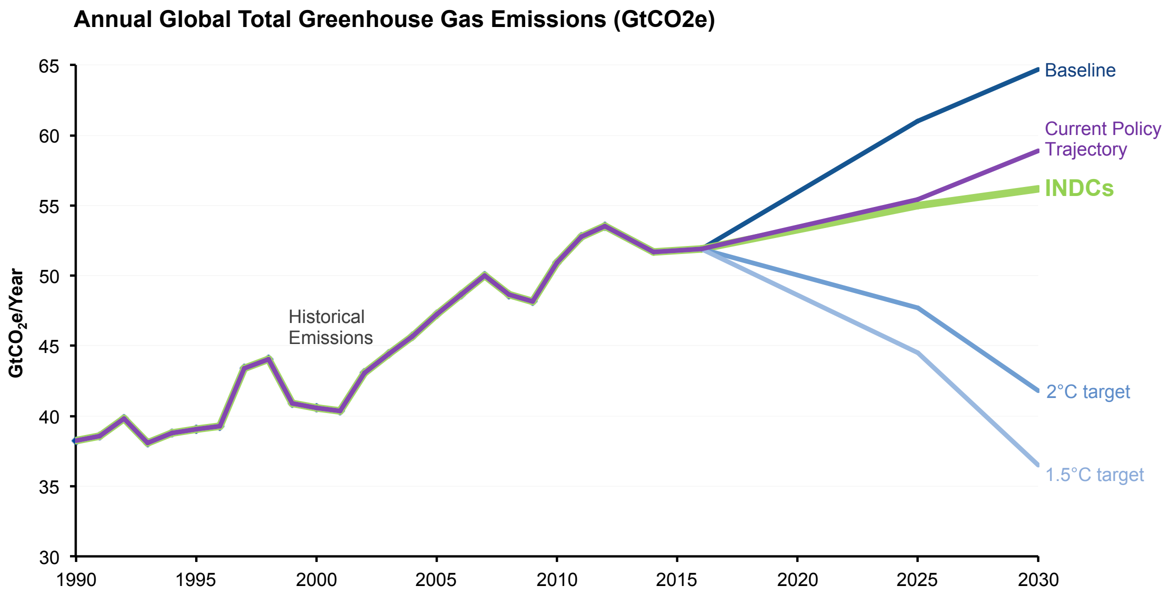
Over the past decade, technology innovation and a favourable policy environment have transformed the energy landscape. Renewable energy sources such as solar PV and wind are now cost-competitive with conventional sources of electricity in many markets, and scaling fast. The annual capacity addition of renewable energy sources has increased strongly since 2000 (see Figure 2), repeatedly beating forecasts.[2]

While transport today is largely powered by fossil fuels, vehicle efficiency has improved, and promising developments are underway in electric vehicle technology. This is aided by a rapid decline in lithium-ion battery costs

Figure 1: Annual global GHG emissions in Gigatonnes CO_2/year[1]

The gap between the current policy trajectory and the pathways to meet climate goals clearly indicates the need for increased and accelerated innovation in sustainable energy

Source of data: UNEP Emissions Gap Report 2017



Baseline scenario: assumption that no mitigation policies or measures will be implemented beyond those that are already in force and/or are legislated or planned to be adopted. **Current policy scenario:** based on the adoption of unconditional components of INDC (Intended Nationally Determined Contributions; submissions by parties that identify actions each national government intends to take under the future UNFCCC climate agreement, negotiated in Paris in December 2015) only. **INDC scenario:** full adaption of conditional and unconditional components of the INDCs.

and by government incentives as well as by hydrogen-based solutions due to the increasing maturity of fuel cell technologies – even though both EVs and fuel cell vehicles are growing from a very small share of the global vehicle fleet. Moreover, many of the fundamental drivers and sources of new technologies and solutions that can affect energy lie mainly outside the energy industry. A Fourth Industrial Revolution is starting to unfold, transforming technologies, solutions and business models in most sectors, and radically changing the way people consume products and services. Some of these, including digital technologies that enable smart grids and energy system efficiency, can be applied directly to energy sustainability challenges and provide new opportunities.

While innovation is happening fast in the above mentioned areas, it remains sluggish in many others. The International Energy Agency (IEA) has highlighted only 3 out of 26 main technology areas that are required to contribute to keep global warming well below 2°C over pre-Industrial Revolution levels, as agreed to in the Paris Agreement at COP 21. The remaining 23 technology areas are not progressing fast enough.[3]

Carbon capture and utilization, hydrogen, advanced nuclear, advanced biofuels, efficient heating and cooling are all examples of technology areas with significant potential but delayed progress compared to areas such as solar, wind and digital solutions applied to energy, batteries and electric vehicles. Specific technologies and smart system solutions that enable technologies to be put into practice are needed.

While governments are taking action, RD&D investments and the speed of innovation lag in other sectors.

Mission Innovation (MI) is an alliance launched at COP21 comprising 22 governments and the EU, representing 80% of global clean energy RD&D and 70% of global GDP. MI members committed to double their clean energy RD&D spending from $15 billion to $30 billion per year by 2021 and to work to make clean energy more widely affordable and scalable in the energy system. MI focuses on seven specific technology areas and cross-cutting issues to accelerate innovation.

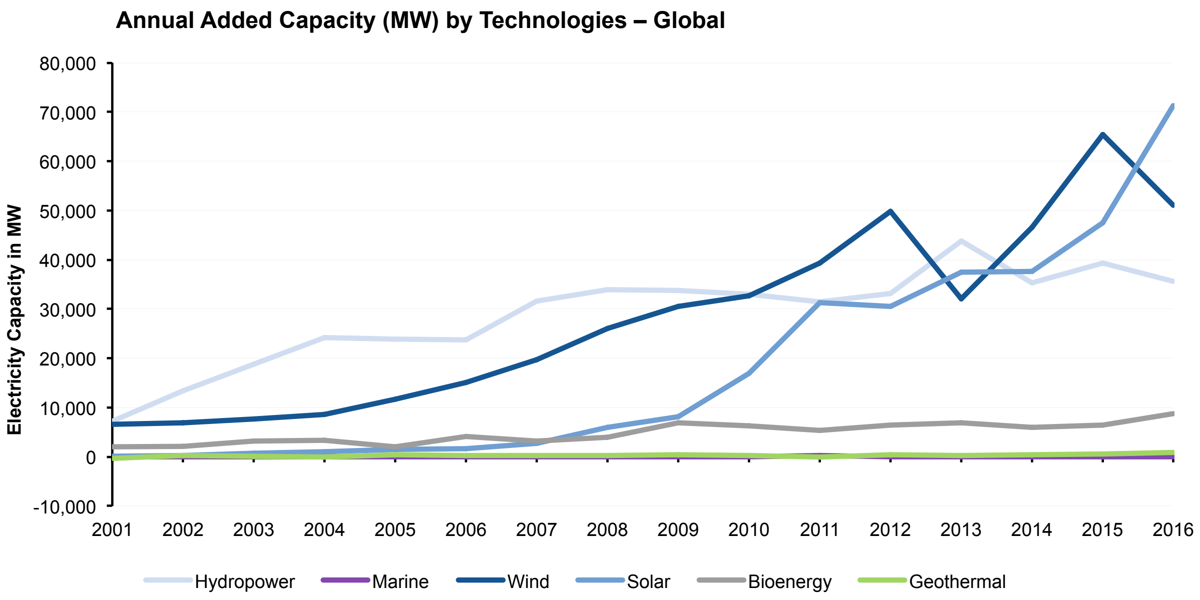
However, high costs, system inertia and long lead times – usually 20 years or more from idea to commercial diffusion – make it challenging for companies or governments to deliver innovation at the pace required.

In just one example, the development and installation of solar PV cells from space research to rooftop took *more than 35 years.*[4] In comparison, other innovation areas such as computing and artificial intelligence, information and communication technologies etc. have evolved rapidly in a far shorter period of time. This is certainly due to those areas having less infrastructure investment needs than energy, but no doubt it also is due to higher investments in RD&D and the need to bring new solutions to market quickly in a sector characterized by short cycles and rapidly falling technology costs.

Figure 2: Annual added capacity of different renewables

Global annual added capacity of wind and solar PV have crossed tipping points, while annual additions of other technologies remain flat

Source of data: IRENA



Information on research and development expenditures per energy technology area is scarce, especially for private-sector spending. However, the World Energy Investment (WEI) 2017 tracks $67 billion of spending on energy research and development worldwide in 2015, based on a bottom-up assessment of spending by public and private bodies. The details are listed below:

– Europe and the United States are the largest spenders, each accounting for 28% of the total, whereas China is the highest spender on energy RD&D as a share of GDP, after overtaking Japan in 2014. Figure 3 shows public funding in different sectors for some IEA countries.
– Most private RD&D goes to oil, gas and thermal power generation, whereas most public RD&D is devoted to clean energy technologies.
– The global investment in clean energy RD&D, $27 billion in 2015, has been flat since 2012.[5]
– While the private sector received 63% of all positive climate-relevant investments in 2016[6], private companies active in clean energy reported investments of $7.2 billion in RD&D in 2016, which represents around 18% of all reported corporate energy sector RD&D spending.
– The public sector contributes more than two-thirds of global RD&D investments in clean energy.[7] However, in contrast to the reported data, private RD&D spending in sustainable energy is estimated to account for a large proportion of a country's RD&D spending, according to tracking of transaction data chains between companies in combination with reported figures of proportional spend on RD&D ("tracking of transactions").[8]
– Early-stage venture capital investments in energy RD&D amounted to around $2 billion in 2015, most of it in clean energy technology.[9]

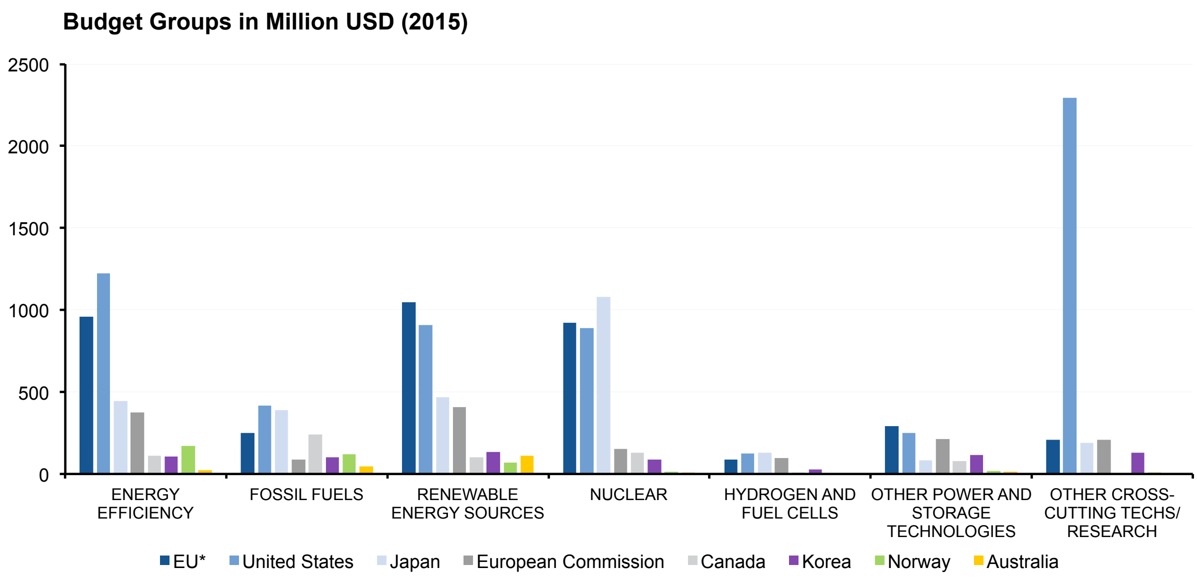
To put things into perspective, the cumulative global RD&D funding on clean energy and electricity networks in 2016 is less than company RD&D spending by top three global IT firms.[10] More funding is not in itself a panacea to solve energy innovation challenges – but clearly it is an important component. Many governments are stepping up investment levels – for instance, those involved in the Mission Innovation pledge to double national government RD&D funding in clean energy. In addition, and critically, more private-sector funding is needed.

Global energy system transformation and solving climate and sustainability issues are huge, multidimensional tasks; accelerating sustainable energy innovation is one vital and achievable part of that effort. What follows are insights gained through the World Economic Forum's project, *Partnering to Accelerate Sustainable Energy Innovation,* combining dialogue events, desktop research and expert interviews to create a view of the barriers holding back the pace of innovation, and ways to overcome those barriers to accelerate progress.

Figure 3: Investments of selected countries in clean energy RD&D by sector

Energy efficiency, renewable energy and nuclear receive the most public RD&D funding

*Source of data: IEA; * including EU member states Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Spain, Sweden, United Kingdom. A large amount of US RD&D spending is allocated to unspecified energy basic research.*



3. Defining the energy innovation system

Key elements of the sustainable energy innovation system – people, catalysts and the innovation process – can align to counter the system's barriers and accelerate the innovation process.

Through expert interviews, dialogue events and research, the World Economic Forum identified the components of a healthy energy innovation system, as well as the roadblocks to accelerated innovation in sustainable energy. By understanding these components, we can begin to identify steps stakeholders can take (see Chapters 4 and 5).

Sustainable energy innovation flourishes in virtual networks and physical systems that cross national borders and involve multiple actors, from established companies and start-ups to academic and government institutions. Catalysts for innovation, such as regulatory policies, public funding programmes and innovation alliances, regulate and influence the system's enabling frameworks, which also contain inherent deficiencies or weaknesses that create barriers for sustainable energy innovations (see Figure 5). These barriers can act in combination to create significant hurdles across all stages of innovation.

People form the core of innovation

Inventors and researchers explore, combine and test new and existing technologies to create breakthrough ideas. Politicians act as influencers, affecting the enabling frameworks by enacting regulatory policies or dedicating public money to innovation programmes, while scientists and academics fill the sustainable energy pipeline through basic and applied research, development and demonstration.

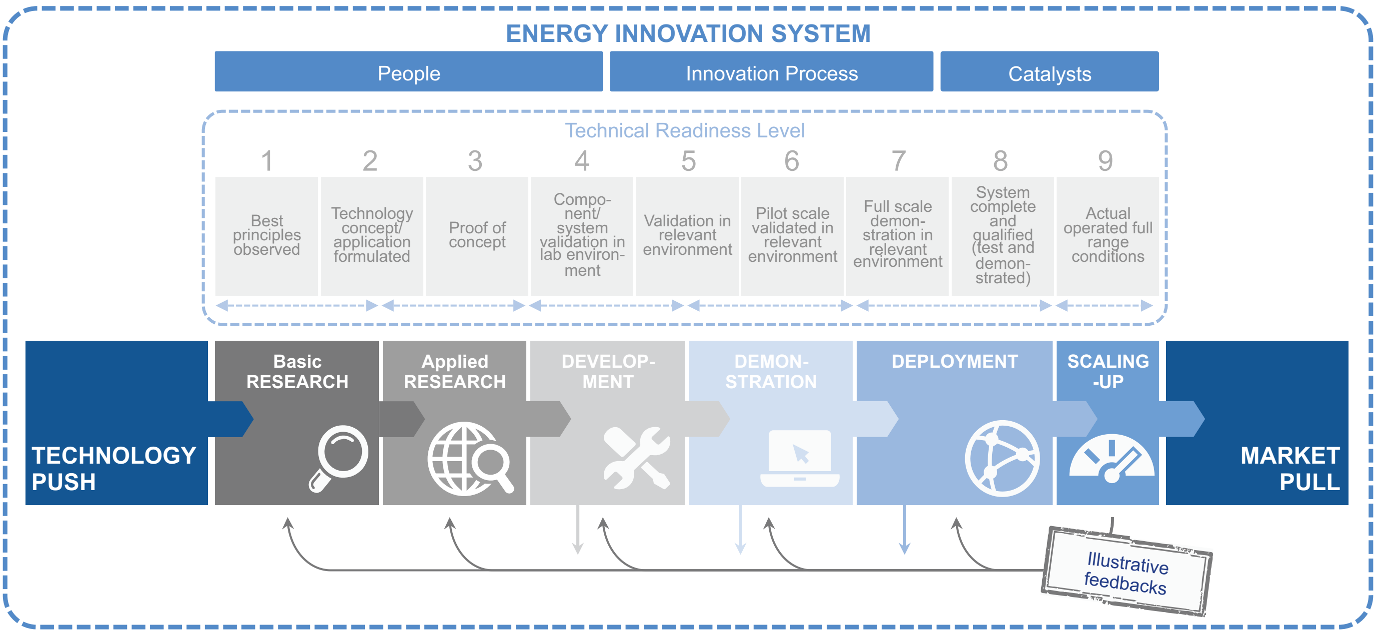
Within the innovation ecosystem, entrepreneurs often bear great risk in bringing innovation to market through start-ups, which are often spin-offs of projects by universities, research institutes or national labs. They work hand-in-hand with private and institutional investors to raise capital to fund progress.

Small or medium enterprises (SMEs) and larger corporates are particularly strong in the deployment and scaling-up of new technologies, often working in cooperation with researchers and innovators. Company-led projects are increasingly financed by institutional investors, requiring financial expertise to develop business plans and conduct complex risk assessments. Finally, salespeople and developers at the supply end also play an important role, particularly in the later stages of the innovation process.

Figure 4: Energy innovation system, innovation process and TRL[12]

The key elements of the energy innovation system are people, the innovation process and the catalysts building the system's enabling framework

Source: World Economic Forum



The human element makes the system work, creating feedback loops and applying lessons learned from experience – all crucial for innovation. As members of society and as customers, people make the ultimate decision to adopt new technologies, shifting attitudes and behaviours that can support further sustainable energy innovation.

Innovation process

The innovation process encompasses basic research, applied research, development, demonstration, deployment and upscaling. The Technical Readiness Level Model (TRL) is increasingly used to assess maturity of technologies and the overall project status.[11] (see Figure 4).

TRL 1–3 encompass the basic and the applied research phases to prove the feasibility of an innovation, while TRL 4–5 include the development phase, first in a lab and then in relevant environments. TRL 6 marks an important milestone in the innovation process, the pilot demonstration in a relevant environment. Demonstration and pilot projects are critical to detect scalable approaches, prove concepts and serve to convince customers, investors and policy-makers of the feasibility of an innovative technological solution.

While it appears simple, the path from TRL 6 to market maturity in TRL 8 is lengthy and complicated, particularly for entrepreneurial innovators facing the "valley of death" to reach market and scale. Efforts to increase quality, introduce standardization, reduce cost and improve manufacturability are not only time- and cost-intensive, they require specialist knowledge that start-ups often lack.

Once innovations reach market maturity and early market deployment, the ability to create economy of scale is critical; it is the tipping point for investments and market uptake. With scale, unit costs typically decrease with increased production and higher order quantities, as standardization, experience-based learning and automation begin to pay off. The cost of financing also typically decreases with scale and maturity of technologies, which the examples of solar and onshore wind illustrate. Across the innovation process, the market factor acts as a pull for new solutions, while investments and efforts in RD&D provide a technology push towards making solutions market-ready and scalable.

The barriers to innovation and the catalysts for acceleration mirror each other

Figure 5 summarizes the key barriers to bringing new technologies and solutions to market: regulatory risks; access to financing; lack of enabling infrastructure and market access; and social and cultural challenges.

Relatedly, the main catalysts that can help overcome these barriers in an enabling framework for innovation are the following:

1. social and industrial trends influencing consumer demands
2. a positive climate for overall innovation[13]
3. regulatory policies
4. public funding programmes
5. multistakeholder collaboration.

These catalysts operate at different speeds and in terms of the degrees in which they can be influenced. Trends affect consumers and the climate for innovation change indirectly over longer periods. But regulatory policies, public funding programmes and collaboration through innovation alliances are directly adjustable by people in shorter timespans. As such, this paper focuses on the near-term catalysts, presented in greater detail in Chapter 4.

Figure 5: Barriers of the energy innovation system
Systemic barriers to sustainable energy innovation system fall into four primary challenges

Source: World Economic Forum

Regulatory risks

- Lack of credibility in policy frameworks creates uncertainty about future policy stringency, timing, nature and durability
- Inability for institutional investors to more quickly depreciate investments in sustainable energy innovation
- Lack of flexibility in policy framework hampers testing of new technologies in real environment
- Lack of perceptible price for GHG emissions in many jurisdictions
- Lack of standard metrics to evaluate sustainability at a circular economy level

Financing

- Policy framework still does not make business plans profitable for many technologies
- Financial valley of death: Lack of patient risk capital available in the sustainable energy innovation system
- Technical risks: Development, deployment, and system integration costs exceed available budget
- Lack of public money available for demonstration projects
- Lack of international funds to invest in international flagship projects

Enabling infrastructure and market access

- System inertia and energy security concerns limit the integration of innovative technologies, such as zero emission generation and demand response in existing networks and markets
- Lack of standardization for better integration and faster scale-up of innovative hardware and digital solutions
- Non-uniform pace of innovation in different components of the system solutions; e.g. electric vehicles and charging infrastructures
- Cyber-security risks and privacy concerns of 4IR solutions are less understood

Social and cultural

- Lack of sufficient public-private partnerships
- Pre-competitive long term collaborations in RD&D are still rare
- Consumer uptake of sustainable energy products is still not satisfactory although clean and economic solutions exist
- Key decision-makers appear to lack knowledge about the crucial importance of speeding up innovation

4. Making the difference: Aligning catalysts for accelerating energy innovation

The framework to enable innovation must ensure that by aligning the near-term catalysts – regulatory policies, public RD&D funding programmes and innovation alliances, described below – the components of the innovation system are established and interact productively to yield better outcomes. We also highlight success factors and examples to identify practices that could be scaled or replicated, as well as to better understand the pathways to faster innovation.

4.1 Regulatory policies

The credibility of the sustainable energy innovation regulatory policy framework is fundamental due to the often long lifetimes of capital stocks, high investments required at every stage of the innovation chain, and the long duration needed for innovation to move from basic research to market deployment.

The "market pull" is often not strong enough to create a fast track for sustainable energy technology innovation, as markets are often unable to put a price on environmental resources or externalities.[14] As such, the regulatory policy framework is the most important catalyst to accelerating sustainable energy innovation by incentivizing investments. However, it needs to be credible because investments are highly sensitive to perceptions regarding the credibility of future policy commitments.[15]

A credible policy framework must incorporate the concepts of effectiveness, stability and predictable flexibility.

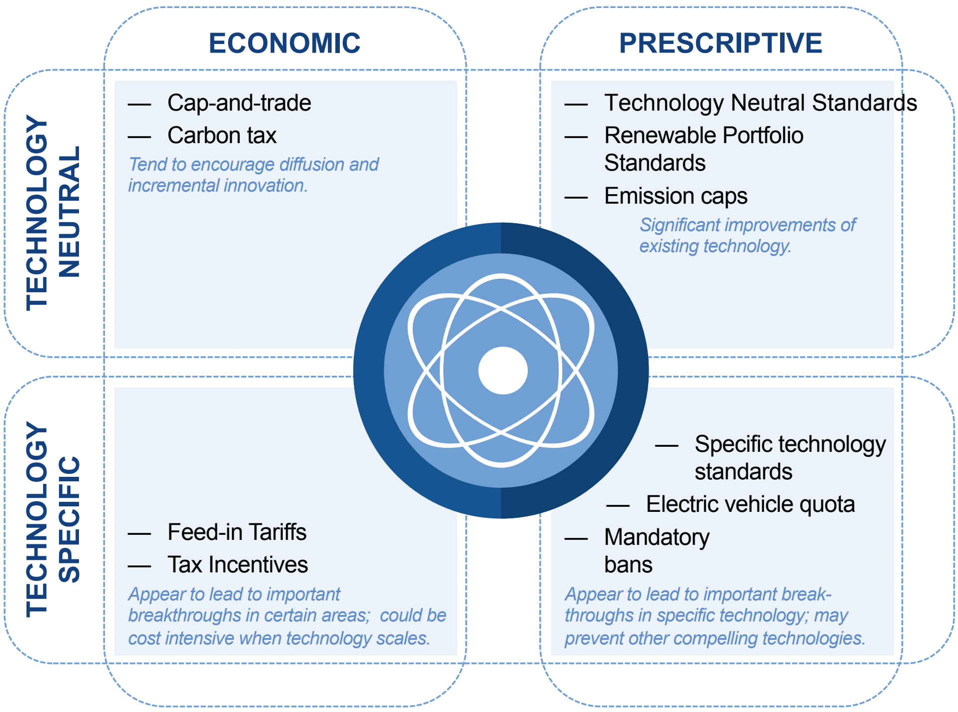
4.1.1 Effectiveness

A credible regulatory framework needs to be both effective in spurring innovation and economically effective for society and consumers, especially if designed to be maintained as these technologies scale. For instance, a subsidy to renewable energies can be effective in terms of driving deployment in the early stages but it becomes costly to consumers if maintained unchanged as the technology reaches significantly lower costs and a larger scale.

Regulatory policies are either prescriptive or economic, and are technology specific or neutral (see Figure 6). Prescriptive policies such as quotas, standards or other direct regulations do not offer incentives beyond a mandated predetermined level and therefore fail to benefit from further improvements without frequent adjustment. Hence, economic policies, which provide incentives by offering benefits for investments in sustainable energy innovations or by pricing negative environmental externalities such as pollution, may be more effective in spurring innovation.[16] However, both economic and prescriptive policies can be effective in regards to innovation in the longer term.[17]

Figure 6: Types of regulatory policies

Source: Bergek and Berggren



Technology-neutral policies seek to stimulate innovation in general or in a specific field (for example, emission-free vehicles) without "picking winners". Technology-specific policies seek to provide leverage to certain technology areas or specific technologies – for example by setting technological-specific standards such as mandating the use of best available technologies (BAT) or quotas.

– *Technology-neutral economic* policies such as emission trading schemes tend to encourage diffusion and incremental innovation and scale-up through pricing and other monetary incentives that generally apply to multiple sustainable energy technologies.[18]
– *Technology-neutral prescriptive* policies such as the European vehicle emissions standards enforce significant improvements across multiple technologies with the objective of abiding by set mandates or regulations.[19]
– *Technology-specific policies* appear to lead to important breakthroughs in certain areas,[20] such as wind and solar through the German-feed in tariff (see Figure 9). However, technology-specific policies may also prevent other compelling technologies from being commercialized and scaled up. The challenge of using technology-specific instruments is to provide innovators enough "space to innovate".

In order for key stakeholders to make informed decisions and invest in new energy technologies, the incentives must be material – regardless of the type of policy or incentive that hopes to influence those decisions.

The majority of experts who participated in the workshops and interviews for this paper agree that a credible policy framework requires a transparent and perceptible price for GHG emissions at levels that can impact investment decisions,[21] as well as a repeal of subsidies for fossil fuels. This is not only important for scaling of technologies that have reached market maturity but also for innovation in new technologies and solutions as it can provide a crucial incentive to innovate.

Fortunately, the number of countries where carbon pricing through carbon taxes or emission trading schemes (ETS) has been enacted is increasing (see Figures 7 and 8). An example is the Canadian carbon-tax plan proposed in 2017 by the Canadian Federal Government that will be enforced in 2018 in provinces that do not enact their own carbon tax. In addition, major economies such as China are working on developing national carbon trading schemes.

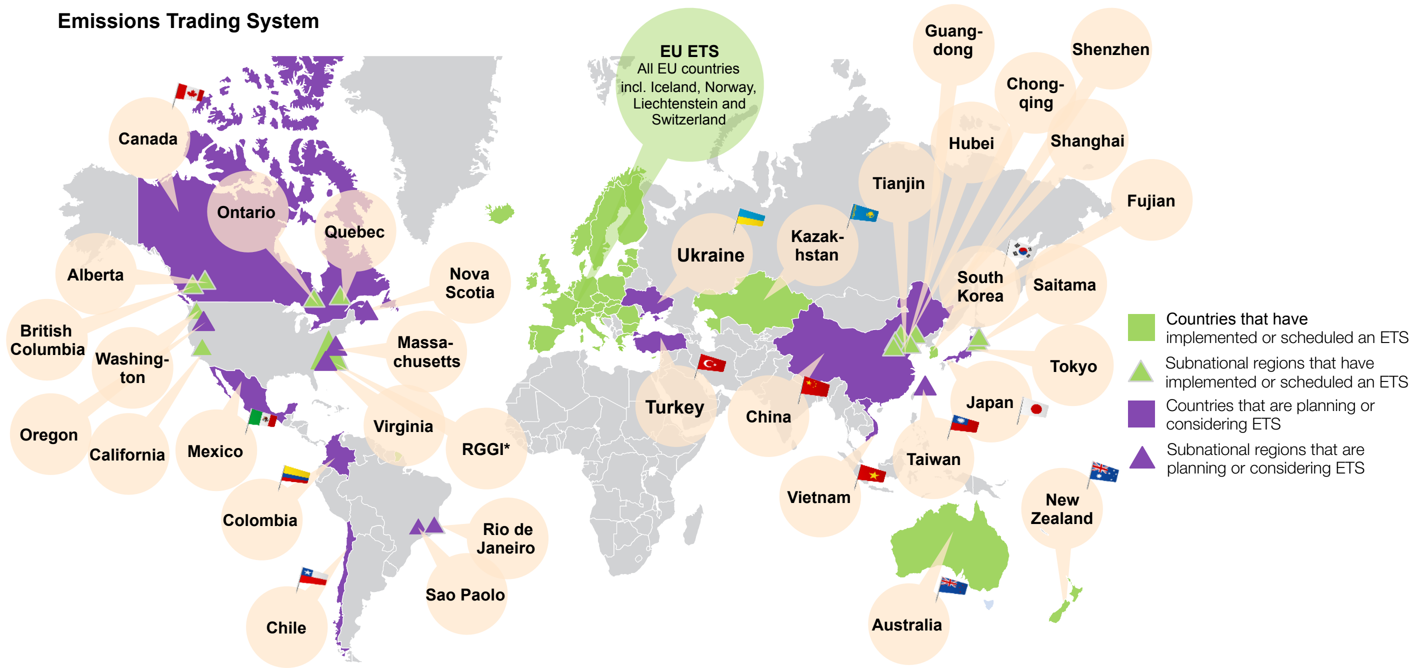
The total number of carbon pricing regulatory policies implemented or scheduled for implementation rose to 47 by 2016. Overall, 67 jurisdictions – representing about half of the global economy and more than a quarter of global GHG emissions – are putting a price on carbon using a carbon tax or an ETS, as shown in Figures 7 and 8. These policies cover about half of these jurisdictions' GHG emissions or 15% of global GHG emissions. As soon as China's national ETS is implemented, this will expand the emissions covered by carbon pricing to between 20 and 25% of global GHG emissions.[22]

Figure 7: Countries and subnational regions that have enacted or are planning or considering a carbon tax

Source: WORLD BANK GROUP, carbonpricingdashboard.worldbank.org

Figure 8: Countries and subnational regions that have implemented or are planning or considering an ETS

Source: WORLD BANK GROUP, carbonpricingdashboard.worldbank.org



*Regional Greenhouse Gas Initiative (RGGI) has been implemented in Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont.

However, further progress is required to make a material difference. First, the price in many jurisdictions is too low to contribute significantly to GHG emission reduction or to the acceleration of sustainable energy innovation. An example is the European ETS scheme, which has led to neither significant GHG emission reductions nor to remarkable innovations.[23]

In practice, a mix of different policies (and funding programmes) is instrumental in leveraging innovations effectively[24], and the policy mix must align with both long- and short-term strategies for energy transition.[25] Thereby, the interaction of different policies with regard to the costs needs to be investigated carefully.[26]

4.1.2 Stability with predictable flexibility

Credible policy frameworks need to be stable enough to encourage investor certainty, reduce business risk and lower interest rates. To unlock private investments and make investments "bankable", incentives need to be reasonable and convey the expectation of persistence.[27] A lack of regulatory credibility not only slows innovation, it can impose significant extra costs on the economy relative to what would be considered "ideal" or second-best regulation.[28] For example, the repeated introduction and expiration of the US production tax credit (PTC) for wind power caused a downturn in investments not just during "off" years but overall due to uncertainty over returns.[29]

At the same time, in a fast-changing global energy environment, a regulatory framework must be flexible to support the development of new technologies that hold the greatest potential, as well as to react to social or technological trends, lasting changes in prices etc. Subsidies or prescriptive policies need to be adapted carefully to effectively pull innovation over longer time spans. Additionally, policies that have not been as effective as intended need to be amended and lessons learned in regards to policy.

Such amendments can even support policy credibility as long as stability is supported through predictable changes that investors can take into account in their business plans. For example, the German feed-in tariff has been amended several times since it was enacted in 2000 (see Figure 9) without hampering its credibility because the changes have been, to some extent, predictable.

Also, regulators will need to innovate themselves and provide a space for businesses to innovate as the technology opportunities are changing. In this regard, the concept of "regulatory sandboxes" can be a useful tool for regulators and companies alike. If innovators are unclear whether a technology or solution complies with regulatory requirements, or is worth incurring the costs of regulatory compliance procedures, it could lead to such new concepts not being tested in a real environment and thereby stifle what could have become a promising breakthrough or learning. Recognizing this, some regulators are taking action. For instance the Energy Market Authority in Singapore has proposed a framework enabling companies to test new products and services in electricity and gas before potentially being introduced in main markets through a "regulatory sandbox". Beyond lowering the hurdle for innovators to test new concepts, this benefits regulators by allowing them to test new types of regulation before they are introduced on a wider scale.

To manage the trade-off between the need for stability and flexibility, the concept of "predictable flexibility" is useful. Policies might be designed with a built-in predictable flexibility, meaning the coupling of incentives with external parameters, for instance, global average prices, production prices, technology costs or others. The Japanese Toprunner programme for energy efficiency is one example of a predictably flexible regulatory environment that pushes innovation and continuous improvement. Likewise, governments can make policies subject to a regular revision and an adjustment within a predictable range. Lastly, governments can also leverage the opportunities of regulatory sandboxes as outlined.

More importantly, to achieve predictable flexibility, policies should be credible, while allowing for flexibility in a plausible manner. Consider these five important factors:

– First, governments need to take a more active role, defining the blurred lines between where and how to act, as well as where *not* to act. This could include establishing effective push-and-pull mechanisms as well as standards for certain technology areas, while at the same time withdrawing public support where it is no longer needed in a predictable manner. The perception that governments will take the actions required to achieve their targets is important.

– Second, regulatory policies and programmes need to be systematically implemented and tailored to the individual technology's value chain and the local innovation system, as well as to externalities. For example, the mass deployment of fluctuating renewable power generation requires adequate grids for distribution, but a lack of (or delay in the) adjustment, replacement or instalment of those grids diminishes the credibility of the political intention to support renewable energies. Another example that could jeopardize government credibility is support for electric vehicles but inadequate facilitation of the requisite charging infrastructure. Systematic implementation also makes the policy framework on the whole more credible and cost effective. For example, a lot of renewable power is wasted when the surplus energy is not distributed or stored. In Germany, end users paid over 0.5 billion euros in 2015 for electricity generated by renewables that could not be distributed.[30] Skilful policy design also needs to take into account the potential intended or unintended side effects of policies in the energy system and beyond. Examples of such unintended consequences could be underinvestment in some technology areas due to preferential regulatory treatment of others, or "rebound effects" on energy demand as a side effect of higher energy-efficiency solutions.

– Third, a credible policy framework requires laws rather than other policy instruments such as plans, declarations, contracts, etc. Clearly, some existing governmental GHG reduction targets are insufficiently supported by laws. In contrast, the Climate Change Acts enacted by the UK in 2008 and the Canadian State of Victoria in 2017 are examples of good practice in regulatory policy creating credibility and sustainability in the energy innovation process.

– Fourth, the policy-making process would benefit from greater collaboration, in particular, through improved communication and relationships with the private sector. An effective and credible policy framework needs to mirror realities on the ground and be designed to overcome barriers; involving relevant stakeholders in a consultation process can be a powerful tool as governments design policies.

– Finally, to be credible and to use their discretion to change policies in a credible manner, governments need to have sufficient highly skilled policy-makers. This includes institutions delegating to an independent expert body to some extent (see Section 5.1, for examples).

Examples of good practices within current policies

Chinese electric vehicles (EV) Quota
The announced Chinese quota on new energy vehicles (NEVs) demonstrated effectiveness even before its enactment following the announcement of several automakers to develop new NEVs. The regulation stipulates that automobile manufacturers with annual sales over 30,000 units must ensure that hybrid or electric vehicles account for 10% of their portfolio in 2019. The cap will increase to 12% in 2020. For non-compliance, material penalties are foreseen as reinforcing the effectiveness of the regulation. The NEV-quota is aligned with the ambitious deployment of grid and charging infrastructure in China.

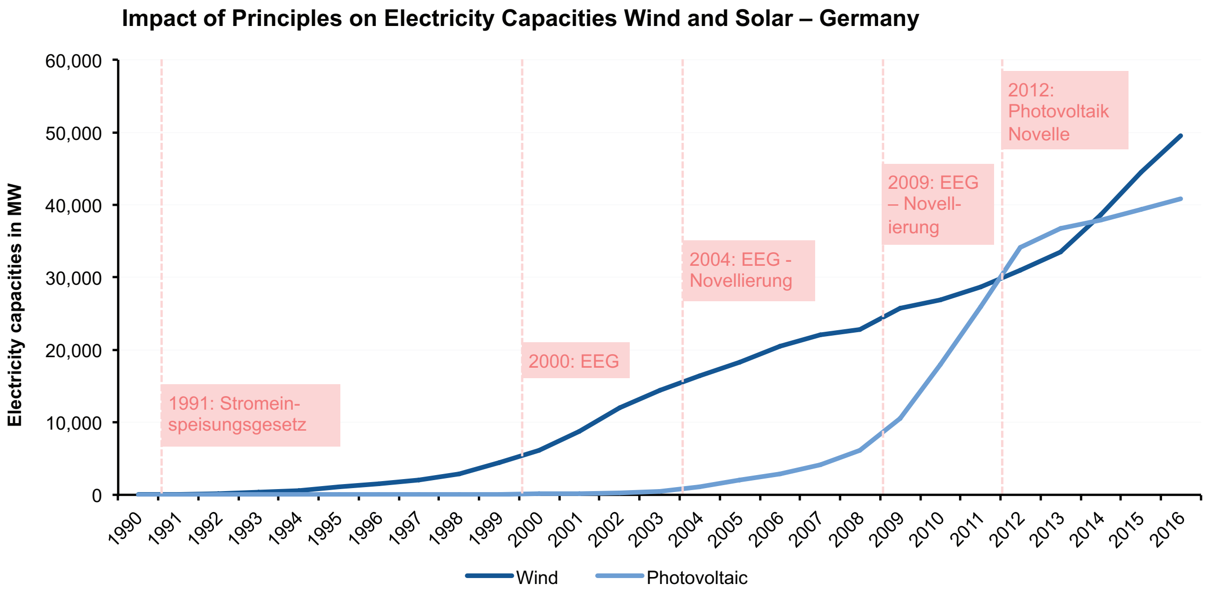
German Renewable Energy Sources Act (EEG)
Enacted in 2000, the EEG still offers effective and stable but cost-intensive support for the deployment of renewable energy sources (hydro, wind and photovoltaic) in Germany. It has contributed largely to the price drop of photovoltaic, especially during 2009 and 2012. It is revised regularly (as in 2017, 2014, etc.), so amendments are to some extent predictable.

California Renewables Portfolio Standard (RPS)
The California RPS is a stable policy for the deployment of renewable energy sources. Enacted in 2002, it sets predictable interval targets for achieving a 50% renewable energy share of electricity generation by 2030. The effectiveness of the RPS is reached by enforcing the standard through penalties on service providers that do not achieve the renewable energy procurement requirement.

Figure 9: Impact of policies on electricity capacities wind and solar – Germany

The German Renewable Energy Source Act demonstrates the positive impact of the policy on sustainable energy deployment.

Source of data: German Federal Ministry for Economic Affairs and Energy, 2017



Emission Reduction Alberta (ERA)

The mandate of ERA is to establish or participate in funding for initiatives that reduce emissions of GHGs or improve the ability to adapt to climate change within Alberta and beyond. ERA actively manages Alberta's Climate Change and Emission Fund, decoupling the investments in innovation from volatile political changes. The fund, established by the Climate Change and Emissions Management Act, delegates the Minister of Environment's power, duties and functions related to the fund to ERA. It is backed to a large extent by industry contributions to the fund when it fails to achieve emission reduction targets.

4.2 Public RD&D funding programmes

Far more public funding is needed alongside higher private-sector investments (see Chapter 1), and the public funding currently available needs to be invested more effectively.

Public funding for energy RD&D can play a critical role in complementing funding from the private sector or acting as seed money to encourage larger private investments. Organized and involved public funding programmes are necessary to support sustainable energy RD&D where market forces – even when supported by regulatory policy framework – cannot deliver all of the investments needed. Public funding includes grants, government support in equity, debt financing (loans, guarantees and risk-sharing mechanisms), public procurement (direct public support to business RD&D)[31], innovation prizes and other instruments. There are positive signs, notably the pledge by Mission Innovation countries to double their national annual spending by 2021 – already representing 80% of global clean energy RD&D funding.

While their magnitude and diversity make it difficult to determine a comprehensive set of success factors, common themes include *active management, market push and collaboration* measures that drive innovation towards deployment.

Active management

Active management by governments or the funding agency can facilitate programme success, provided it is based on relevant competence. This may even include departing from traditional technology-neutral attitudes to promote technology-specific solutions, as appropriate. ARPA-E and the SunShot Initiative both enjoy active project management and are permitted to fund or terminate projects based on their targets and expectations.

Many governments actively shift support from public research towards supporting business innovation and entrepreneurship to boost job creation and economic competitiveness.[32] The European KIC Innovation incubator programme is one example of this, as well as more recent EU efforts to coalesce a consortium of companies to develop a competitive battery technology industry in Europe.[33] Other countries have made similar efforts.

Market push

Pushing public RD&D to target specific real-world challenges that current technology can't solve, and having a credible route to market from the RD&D stage, are two important components of successful innovation programmes. These can unlock or spur the critical private investment needed to take solutions to market but they are often restricted by high risks or capital requirements. This includes the early to mid stages of the innovation cycle, where governments traditionally play an important role with public spending in demonstration projects. Ideally, this is done in collaboration with private partners, cooperating in areas that depend on demonstration projects where the costs or risks are too high for the private sector to find them attractive (e.g. CCS). Figure 10 clearly indicates that public spending in demonstration projects is still low, keeping in mind that the differentiation between RD&D and demonstration might be inconsistent in the data.

Securing first buyers and markets is often a critical barrier to developing innovative yet often costly solutions. Public procurement could become a more mainstream way of encouraging sustainable energy innovation by providing first markets, as commonly used in the defence industry, in addition to an innovation-enabling regulatory policy framework and other direct forms of public support (see Section 5.4). However, public procurement can be constrained by international trade commitments or domestic competition rules. Additionally, open-trade policies will have an impact on the size and attractiveness of markets for innovative technologies and solutions, a theme that is not covered in this report.

Other measures that help push innovation along the chain include the assistance of funding agencies to find additional financing after initial project conclusion, support for marketing or networking, and assistance with patent applications. On a governmental level, a push to market should include follow-up programmes.

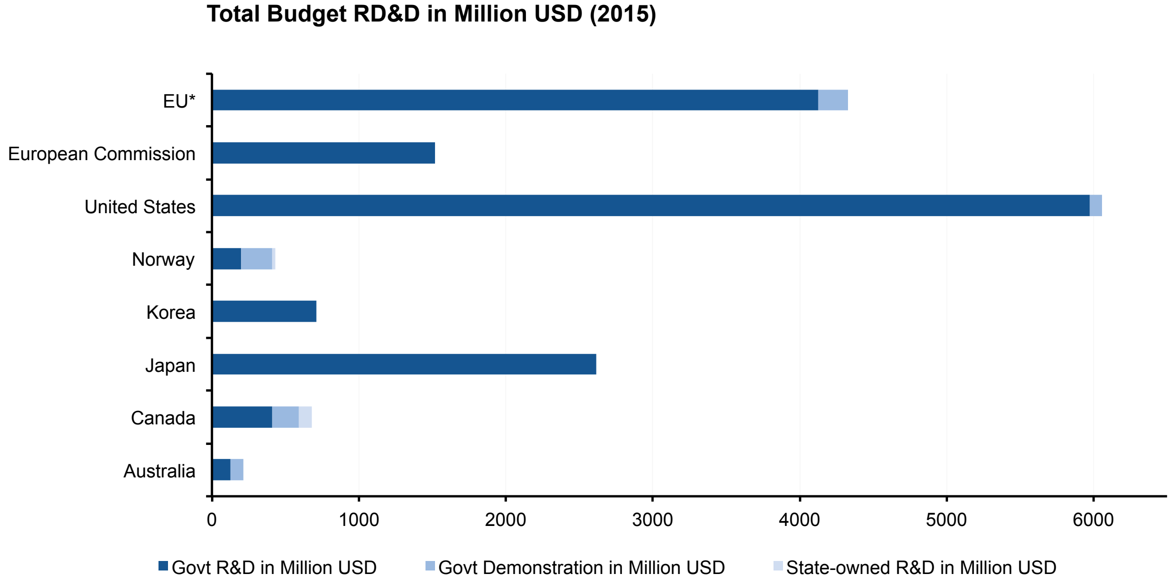
Collaboration

Due to proven effectiveness of collaborative RD&D (see next chapter), many experts consider programmes with a collaborative RD&D approach, such as the US SunShot Initiative or the German Kopernikus program, as particularly successful. Collaboration among public funding beneficiaries can include the exchange of knowledge, coordinated research agendas, effort sharing, measurement and technology standards, and joint research teams.

Additional collaboration with the funding agency ensures a common understanding of the projects and gives the agency the chance to learn but also leverage projects through the agency's project knowledge.

Figure 10: Spending of selected countries and the EU Commission in clean energy RD&D
Government spending on demonstration remains low

Source of data: IEA; * including EU member states Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Luxembourg, Netherlands, Poland, Portugal, Slovak Republic, Spain, Sweden, United Kingdom.



Examples of good practices in funding

Japan's hydrogen programme

Japan's Mission Program on hydrogen and fuel cells covering production, storage, transport and use was developed as part of the drastic revision of Japan's energy strategy after the Fukushima nuclear accident in 2011. The programme relies on public-private partnership and a detailed roadmap developed jointly with the private sector that sets interval targets and corresponding measures to enhance and scale up the hydrogen supply chain, generation and economy until 2040. Japan's ambitious programme is centrally controlled by the Ministry of Economy, Trade and Industry.

Advanced Research Projects Agency-Energy (ARPA-E)

The ARPA-E, established within the US Department of Energy (US DOE), actively sponsors research and development projects not yet mature enough for private-sector investment funding. Highly competent programme managers and experts take a hands-on approach. Projects are based on milestone financing, programme managers stay actively involved, and ARPA-E supports projects on a contractual basis. This allows ARPA-E to intervene when necessary, changing the targets or technical approaches, or terminating projects that fail to achieve the agreed milestones. Nearly half of the projects have published the results of their research in peer-reviewed journals; many projects have obtained patents for their energy technologies or received additional funding from the private sector to continue their work.[34]

SunShot Initiative

The US DOE SunShot Initiative funds collaborative RD&D projects at all stages of the innovation process, including demonstrations, in an effort to make solar energy cost competitive. These funding opportunities encourage cross-sector collaboration and partnership based on the SEMATECH model (see section 4.3). In 2017, SunShot reported the utility-scale PV cost target was met three years earlier than expected.

German Kopernikus programme

Kopernikus is a collaborative research initiative focused on accelerating the transition to renewable energy by driving the evolution of the existing energy system through funding innovation in future grid structures, power-to-X, industry processes and energy systems integration. The frameworks of those projects taking place in the relevant environment are designed to be dynamic and market oriented, enabling flexible adoption and linking sustainable aspects (economic, social and political, and technological) to ensure enduring impact.

4.3 Innovation alliances

Innovation alliances can play an important role in accelerating energy innovation, and their potential is far from fully exploited.

While regulatory policies are most critical, innovation alliances also serve an important, mutually beneficial purpose.[35] Innovation alliances can be public, private or involve combinations of types of stakeholders. Joint ventures between two or more companies to develop specific technologies can obviously play an important role in innovation but they are not included in the scope of what is meant by innovation alliances in this paper. Successful factors in the innovation alliances that emerged through expert interviews include *membership*, *involvement of key decision-makers* and *impact orientation.*

Membership

Successful alliances need to involve "the right players", particularly those with different areas of focus who can influence or manage the range of issues a given alliance might have. The right players depend on the alliance's purpose and targets.

For example, an alliance focused on the RD&D benefits from a strong heterogeneous membership that might include corporates, start-ups, research institutes and universities.

An alliance that aims to deploy a specific technology will need to include significant companies dealing with that technology in its membership.

Involvement of key decision-makers

At the same time, key decision-makers can act as champions of the alliance, as do the ministers in Mission Innovation or the CEOs involved in the Oil & Gas Climate Initiative. The involvement of key decision-makers helps to improve the activity levels of the members in the alliance.

Impact orientation

The Forum identified that successful alliances often communicated a clear and transparent purpose. They also established well-defined targets and appropriate measures, as well as actions for achieving those goals and progress milestones.

Innovation alliances between new and established companies can be particularly fruitful for early-stage and capital-intensive innovations, since they combine the innovation from start-ups with financial and organizational resources from the incumbents.[36] However, such alliances are sometimes hindered by differing cultures within the companies or competitive concerns. Other private alliances go beyond RD&D to focus on networking, knowledge-sharing or active lobbying to promote a certain technology.

Public alliances such as Mission Innovation are in a position to share good practices, or more ambitiously, align policy frameworks or mission programmes (see Section 4.4) across borders. In addition, joint investments in an international fund are conceivable (see Section 5.2).

Much more private investment and public-private collaboration in RD&D is required, particularly around TRL 6–8. Collaborative measures can increase success as well as cost efficiency through resource and risk sharing, as well as tapping in to complementary expertise.[37] Additionally, by focusing on the precompetitive phases, antitrust laws need not come into play.

There is a particular need for a more symbiotic relationship between the public and private sector in the technology innovation process[38], focusing on specific "sweetspots" for collaboration. This could be practically implemented by jointly defining roadmaps (see Section 5.4) or through collaboration on demonstration projects to leap from TRL 6 to TRL 8 (see Figure 4) and overcome "valleys of death" in high-potential but hard-to-accelerate areas like, for example, CCS. Such collaboration could effectively unlock private investments that are typically low in these areas. Estimates show that private companies added $25 for every dollar spent in the US on public RD&D in renewables but only $0.56 for CCS[39]. The Hydrogen Council is one alliance that explicitly underlined the need for collaboration between private and public in its recently published roadmap for hydrogen[40].

Learning from the semiconducting industry

An example of a successful collaborative approach in RD&D which might serve as model for the sustainable energy innovation system is the Semiconductor Research Cooperation[41] (SRC) and SEMATECH (Semiconductor Manufacturing Technology).

SEMATECH was founded in 1988 with the aim of revitalizing the US semiconductor industry by finding ways to reduce manufacturing costs and product defects[42]. Both SRC and SEMATECH formed collaborative groups, including universities and national labs, to co-develop cutting-edge semiconductor design or manufacturing innovation in the pre-competitive space. In the case of SRC, thousands of international partners became involved.

The successful US DoE's SunShot programme was designed based on the experiences of the SEMATECH programme[43]. The EU Fuel Cell and Hydrogen Joint Undertaking (FCH JU), an independent entity that manages EU funding money in a public-private partnership, is another example of a programme with a strong collaborative approach.

Examples of good practices in innovation alliances

Mission Innovation (MI)
MI is a public alliance focused on the acceleration of global sustainable energy innovation by doubling early-stage RD&D investments for this sector until 2021. MI counts 22 countries and the EU among its members, including the world's leading economies. This represents 70% of the global population, including the five most populous countries, with over 80% of clean energy RD&D budgets. Ministers represent MI members and meet annually to push the energy innovation agenda at the senior political level. MI countries co-lead more specific work to advance specific innovation issues.

Oil & Gas Climate Initiative (OGCI)
Founded in 2014, the OGCI is a voluntary CEO-led alliance of ten leading oil and gas companies that collaborate to reduce greenhouse gas emissions by jointly investing in research projects and combining research activities. The CEOs are personally invested in steering and leading the initiative, fostering engagement and leadership that have transformed the companies' approach to collaboration on climate-related issues. For example, the CEOs jointly issue the annual report on the activities of OGCI.

Chinese Energy Storages Alliance (CNESA)
The CNESA, founded in 2009, is China's first professional organization with the purpose of promoting energy storage in China while remaining technology neutral. CNESA members include various important energy storage companies, power-sector companies and national as well as international experts focused on the development of industrial policies. To create impact, CNESA organizes China's most important trade fair on storage, maintains data, publishes white papers and hosts events. In addition, the CNESA is implementing a demand-response pilot programme on behalf of the Beijing city government.

Energyweb Foundation (EWF)
Established in 2017 as a global non-profit organization, the EWF focuses on demonstration and market release of early blockchain applications. Demonstrating exceptional orientation on impact, the EWF recently released to the public a blockchain and application layer test network to be used by start-ups and developers for the testing of decentralized apps using blockchain technology. The release of an operational EWF blockchain platform is envisaged for 2019. Around this open-source IT infrastructure, an environment of users, application developers and infrastructure providers will be established that already counts over 100 members.

4.4 Mission programmes

"Mission programmes" can generate breakthroughs in various technology fields by bringing technologies closer to market maturity, demonstrating viability, lowering costs and convincing customers and investors. These programmes can be particularly useful in areas that require large investments, deep technology developments, sustained efforts and system innovation and deployment.

By definition (Foray et al.[44]), a mission programme denotes a systemic, bold and long-term approach by governments to develop or deploy a certain technology area by aligning policies, public RD&D programmes and public-private collaboration with a concrete aim ("mission"). Central coordination, an increased budget and intensive involvement of the private sector are key factors.

The Japanese hydrogen and Danish wind programmes in the 1980s and 1990s are examples of mission programmes. Consequently, Japan spends more on public RD&D for hydrogen and fuel cells than the US, and more than two-thirds of the spending of the EU Commission, with the 21 member states included, as demonstrated in Figure 3.

Criteria for designing mission programmes[45] include:

- Establish intensive public-private partnership from the outset
- Define clear targets (mission) and a comprehensive roadmap for the partnership
- Employ several different technical solutions for the mission, and fund RD&D in public research as well as in the private sector
- Address identified roadblocks through tailored RD&D programmes
- Finance demonstration projects and support rapid widespread adoption of technology solutions through policy frameworks that create market and/or public procurement
- Ensure diffusion of data and knowledge to the furthest extent possible
- Involve end-users
- Ensure a balance between decentralization and centralization.

The following are examples of technology areas that could likely benefit from mission programmes:

- CCU&S and other "carbon-negative" technologies
- Hydrogen economy
- Ultra-low emission buildings
- GHG free transport
- GHG reduced steel, cement and aluminium production
- Advanced nuclear
- Ocean energy.

Realistically, most mission programmes are national, but the coordination of mission programmes across nations can be even more powerful, as they will avoid duplication and create collaborative efforts. To achieve significant acceleration of energy innovation, several countries could run at least one mission programme in a coordinated manner, or more ambitiously attempt cross-border collaborative mission programmes.

5. Opportunities for step-changes to accelerate sustainable energy innovation

As discussed in previous chapters, a step-change in energy innovation is both required and achievable, but it requires action on several fronts. The challenge of accelerating innovation and unlocking its full potential cannot be overcome by governments, innovators, research institutes or the private sector alone, but needs instead effective collaboration involving multiple stakeholders. And while there is no silver bullet, effective regulatory policies, public innovation programmes and innovation alliances can take us a long way.

By replicating good practices and exploring bold new ideas, sustainable energy innovation can take a leap forward. While the merits, feasibility and appetite for those ideas require further exploration, we present them for consideration here.

5.1 Create institutions for energy innovation

The long, complex and fragmented innovation process calls for an institutional approach that takes a systemic perspective of the energy system and encourages strong collaboration among many stakeholders. National institutions focusing on energy innovation can be instrumental in connecting isolated groups of experts and plugging the gaps that prevent faster conversion of basic research to commercially feasible projects, thus taking a longer-term view and avoiding problems of shorter political cycles. Furthermore, they can improve access to early-stage finance, allow better knowledge sharing through research collaboration, and provide resources for demonstration and implementation in a timely and well-targeted manner or enable innovation through more systematic use of “regulatory sandboxes”.

The ARPA-E agency in the US, and the EU’s KIC-InnoEnergy programmes are good examples of institutional approaches to energy innovation. These programmes employ a streamlined project-approval process, portfolio approach, hands-on relationship with project awardees, and a support community of venture capitalists (VCs), companies and universities to move innovations faster to market. These agencies, while seed-funded by the public sector, have managed to spin off a number of companies, forge industry partnerships and raise substantial private capital as well. Replication in different countries will depend on national circumstances and may require customization of rules and procedures accordingly.

To be effective, institutions for energy innovation will require highly qualified government staff stewarding investments in “high-risk, high-reward” projects, a thriving network of research collaborators from academia and industry, and well-defined pathways for innovators and entrepreneurs to connect to experts in industry and government. An institutional approach will help ensure progress irrespective of changes in the national political climate, encourage capacity-building of stakeholders, and encourage the sharing of methodology among institutions in other countries.

5.2 Establish an independent international fund to finance energy technology projects, blending public and private sources of capital

As highlighted earlier, funding in clean energy RD&D falls short of what is required to effectively accelerate innovation, and large investments in breakthrough technologies for energy innovation pose risks that are greater than what individual countries or companies can undertake.

An international and independently managed entity that pools RD&D funding from interested countries, as well as from the private sector and philanthropists, could potentially have significant impact if well designed and supported by a critical coalition of interested stakeholders.

National economic development priorities, capacity-building targets and competitive advantage concerns require countries to invest locally. Nevertheless, the pooling of funds and resources internationally can help meet RD&D needs in capital-intensive innovation areas in their pre-competitive stages of development, as well as improve cross-border expert collaboration and knowledge transfer. Such a global entity could also help identify high-potential investment opportunities across different technology areas globally and promote the effective allocation of RD&D funds to solve common problems too large, costly or risky for any one nation or company.

To test the idea and incubate the concept, the proposed global entity could employ existing multistakeholder collaboration platforms such as Mission Innovation, whose members pledged to double their public-sector RD&D funding by 2022. For instance, a specified portion of the money pledged could be used as seed capital for a global fund from a group of interested countries. This fund could then also attract further investment from private companies, philanthropies and institutional investors with long-term capital who are looking to share risks and projects at scale.

By diverting a portion of domestic clean energy RD&D funding to an international fund pool, countries can provide better market access to innovative technologies and solutions, collaborate on innovation agendas in specific technology areas, and offer a platform for private-sector investment in sustainable energy innovation. The entity could also include payback mechanisms for successful ventures to lower the long-term costs. Naturally, the feasibility of such an entity will depend on a critical mass of contributing countries and private-sector appetite, while overcoming IPR and licensing concerns, etc.

5.3 Develop instruments for public-private co-investment

The effectiveness of public-sector RD&D investment can improve through better targeting of grant recipients that have higher chances of commercial success. Co-investment with venture capitalists employs their experience and knowledge to help choose RD&D grant recipients, particularly in the early stages of innovation.

Even if existing RD&D grants are in theory available to companies backed by private smart money, "classical" RD&D grant programmes are generally not compatible with the needs and requirements of high-quality venture funds. The grant application process is an administrative burden for a private investor, especially if public funding is uncertain. The timing of "calls for proposals" of classical RD&D grants also may not always coincide with the timing of the funding requirement.

The proposed "co-investment" should therefore remove the uncertainty and time lags, while guaranteeing that only top-quality companies receive funding through a transparent procedure. The process should provide for semi-automatic grant co-financing for investments by venture funds specializing in science- and RD&D-based companies. They would pre-qualify for the VC funds to help them access the co-financing automatically without lengthy separate applications for each of their new investee companies. This pre-qualification could be based on certain eligibility criteria, similar to the co-investment instrument for angel investors, the European Angel Fund scheme, run by the EIF.

The investment burden on the public sector in the proposed "co-investment" could depend on the maturity stage of the investee company. Early funding rounds could have a higher contribution from the public sector with a lower cap on investment in order to minimize any downside. Later funding stages could then have equal contributions from public sources and venture capital, with a higher cap on the funding given the capital-intensive nature of commercialization.

If properly designed, such an instrument would not only stimulate more private money into breakthrough energy projects, but it would also significantly improve the success rate or overall impact of public RD&D grants.

5.4 Co-define energy technology roadmaps through public-private collaboration

Technology roadmaps support the strategy and planning of technology development by aligning innovation targets with knowledge and resource requirements. There has been significant attention to development of technology roadmaps, both domestically and internationally.[46, 47] However, many of these individually developed roadmaps still cannot bridge the technical and financial "valleys of death" that remain.

Co-defined technology roadmaps, developed through the collaboration of the public and private sectors, can be instrumental in attending to multistakeholder perspectives, providing an integrated approach to fast-track developments from the early stages of technology development, identifying bottlenecks, helping to preempt risks, and shortening the time to market through appropriate resource mobilization. Given the systemic implications of sustainable energy innovation, cross-industry collaboration with stakeholders from the public sector and civil society is essential to develop targeted actions that minimize unforeseen risks and externalities.

Collaboratively developed technology roadmaps would be better positioned to enable innovation in areas where a product/service involves different components and supply chains, e.g. electric mobility, which requires simultaneous innovation and standardization across electric vehicles, charging infrastructure, battery modules, inverters, etc. for faster scale-up of low or zero emission transport. The roadmap for hydrogen economy[48] developed by the Hydrogen Council and the Offshore Wind Accelerator[49] in the UK are both good examples of co-developed technology roadmaps with cross-sectoral participation and well-defined pathways for engagement with policy-makers.

5.5 Mainstream public procurement of pre-commercial energy innovation

Public procurement can be a strong driver of innovation, while at the same time raising the quality of public services in markets where the public sector is a significant buyer of goods and services.

The public sector is a significant consumer of energy in the form of public transport, street lighting, centralized heating, public buildings, hospitals, schools, universities, etc. Moreover, in countries where public-sector enterprises are engaged in power generation or in exploration and production activities, innovation procurement can move further up the energy value chain.

Strategically designed public procurement programmes have the potential to scale up the deployment of proven technologies and services as well as stimulate RD&D for innovative solutions.

For proven technologies and solutions, public procurement is primarily used as a "demand side" instrument, intended to improve their diffusion in the market and cost competitiveness through economies of scale. For example, sustainable public procurement policies have helped in the diffusion of energy efficient solutions for lighting, buildings and heating, and low-emission transport.

However, public procurement can also play a critical role in supporting RD&D on innovative solutions. Pre-commercial procurement of innovative solutions can be explored as a means of assisting early-stage technologies in areas where no commercially viable solutions exist, such as CCUS and advanced materials. Public procurement procedures for early-stage solutions will need to be forward-looking, focus more on outcomes than on specific technologies, and allow for experimentation among competitive providers from the private sector. These strategies can be designed as a preparatory exercise targeted towards mitigating technology risks for innovative solutions before large-scale commercial adoption.

The European Assistance for Innovation Procurement Initiative[50] offers useful guidelines on pre-commercial RD&D procurement. However, public procurement should not be seen as a substitute for other instruments, such as RD&D subsidies, regulations and provision of research infrastructure, but should complement these policy instruments[51].

5.6 Super-transparency of government RD&D spending

Accelerating innovation in sustainable energy is a globally shared concern. Countries across the world have expressed an urgency to act and have committed via both national and multilateral initiatives to promote innovation in transformative sustainable energy solutions.

There is an urgent need for more transparency on sustainable energy RD&D expenditure to monitor these initiatives. Governments could lead the way on increasing transparency as they are less affected than the private sector by competitive concerns, and they have an interest in raising awareness among the private sector and innovators about government programmes and funding opportunities. Major companies, let alone smaller, innovative start-ups, are often not aware of the multiple government funds and programmes they can exploit.

The enabling framework of Mission Innovation offers opportunities to share easy-to-access information related to country-level, technology-specific RD&D expenditures and programmes, estimates on corporate RD&D spend, and private research trends[52]. More transparency on RD&D expenditures and innovation trends will help stakeholders monitor the effectiveness of spending on specific technology areas, as well as allow better use of available resources and prioritization of focus areas.

Table 1: Mapping good practice catalysts to barriers

Good practice catalysts that tackle identified barriers			
Topic	**Barrier**	**Good practice catalysts or idea to overcome barrier**	**Reason for effectiveness**
Regulatory policy framework			
1.	– Lack of credibility in policy frameworks creates uncertainty about future policy stringency, timing, nature or durability	– See Section 4.1 – Create credibility by effective and stable but predictable flexible policy framework – Active role of governments: perception is needed so that governments will take measures necessary to achieve targets – Enact laws for important targets. – System integration – Collaboration in the development process of policies with private sector. – Highly skilled policy-makers – See bold idea in Section 5.4	– Credibility in policy framework is most important in unlocking private investments – Cross-industry collaboration with stakeholders from the public sector and civil society is essential in developing targeted actions that minimize unforeseen risks and externalities
2.	– Lack of flexibility in policy framework hampers testing of new technologies in real environment	– See Section 4.1 – Regulatory sandboxes can help test new technologies, for example, blockchain in the energy sector in real environment	– Demonstration of system integration in sandboxes can help to overcome security concerns in the energy system
3.	– Lack of a perceptible price for GHG emissions in many jurisdictions	– Enact carbon price instruments such as ETS, carbon tax or both – Canadian Carbon Tax Plan – See Figures 7 and 8	– A perceptible price for GHG emissions contributes to make GHG emission reduction bankable
Financing			
1.	– Policy framework still does not make business plans profitable for many technologies	– See Sections 4.1 and 4.2 – Create effective and stable pull mechanism – German feed-in tariff, California renewable portfolio standard	– Incentives need to balance absence of sufficient technology pull by market – Outcome-based regulations to sufficiently reward high-risk investments
2.	– Financial "valley of death": little long-term risk capital available in the sustainable energy innovation system – Technical risks: development, deployment and system integration costs exceed available budget	– See Section 4.2 – Public financing of demonstration projects – Public or private incubators like Kic EIT InnoEnergy[53] – See bold idea in Section 5.3	– Proving viability in real environment creates confidence in a technology – Incubators support start-ups comprehensively so they are able to concentrate on business development – Fast and uncomplicated public co-investment could help innovators to find financing partners

Good practice catalysts that tackle identified barriers			
Topic	**Barrier**	**Good practice catalysts or idea to overcome barrier**	**Reason for effectiveness**
3.	– Lack of international fund to invest in international flagship projects	– See bold idea in Section 5.2.	– An international fund could finance flagship RD&D projects with best international knowledge regardless of country interest
4.	– Inadequate public funding for demonstration projects (see Figure 10)	– See Section 4.2 and Figure 10 – Public-private partnerships for demonstration projects – Public procurement (see bold idea in Section 5.5).	– Demonstration projects are important to convince customers, investors and policy-makers of the feasibility of a technological solution
Enabling infrastructure and market access			
1.	– System inertia and energy security concerns limit the integration of innovative technologies and solutions in existing networks and markets	– Technological sandboxes can help test new technologies in the energy sector in real environment without risk for security of supply or the infrastructure	– See above for effectiveness of demonstration projects
Social and cultural			
1.	– Lack of sufficient public-private partnerships in the energy innovation system	– See Sections 4.1–4.3 – Collaboration on demonstration projects – Joint road-mapping – Involvement of private sector in the policy development process – See bold idea in Section 5.5	– Effort sharing – Joint road-mapping – Involvement of private sector in the policy development process to improve credibility and effect
2.	– Consumer uptake of sustainable energy products is still slow	– Incentives for customers – Carbon tax – The Indian Super-Efficient Equipment Program (SEEP) – See Section 5.5	– Incentives for customers can support consumer uptake, e. g. for electric vehicles

6. Concluding remarks

Our report on the preliminary results of our research is just the first step in our efforts to support transformational change in sustainable energy innovation. The World Economic Forum has identified important barriers that need to be addressed, as well as adjustable catalysts for acceleration and good-practice examples for guidance.

In continuing the Partnering to Accelerate Sustainable Energy Innovation project, we will explore opportunities to implement some of the recommendations, and the Forum will continue its collaboration with Mission Innovation, potentially acting as a platform for other innovation alliances.

The "bold ideas" presented here are intended to spark discussion, and it is strongly hoped that some of these ideas will go beyond debate and be successfully implemented.

7. Acknowledgements and disclaimers

The views expressed in this white paper are those of the author(s) and do not necessarily represent the views of the World Economic Forum or its members and partners nor those of KPMG and individual contributors and their organizations listed below.

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