IRENA
International Renewable Energy Agency

IRENA INNOVATION WEEK

The Age of Renewable Power

Summary report

June 2016

IRENA Innovation Week

Summary Report

10 – 13 May 2016
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For further information or to provide feedback, please contact Francisco Boshell: FBoshell@irena.org

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IRENA Innovation Brief

Conclusions from IRENA's first Innovation Week, 10-13 May 2016 in Bonn

I. The technology to push a global renewable energy transformation in next two decades is already here. But more innovation is needed in policy formulation and business models

Innovation has created technologies that can transform the power sector from fossil fuels to renewables over the next twenty years. This includes advances in material sciences, hardware and software, technical systems configurations or "architecture", and smart grids.

But technology is not sufficient. Rapid innovation is still needed to create the business practices and policy frameworks to make that happen, both at a ***systemic level*** - ie. new business models, market design, regulation and policy instruments, and financing – and at the ***operational level*** – such as consumer engagement, supply side management and demand response.

Realms of Innovation necessary for Renewable Energy

- **Technological innovation**, such as from material sciences, hardware and software, technical systems configurations or "architecture", smart grids and grid services.
- **Systemic innovation**, such as new business models, market design, regulation and policy instruments, institutional and policy frameworks, financial instruments.
- **Operational innovation** in system operation and management that result from advances in ICT, including consumer engagement, supply side management, demand response and web-enabled "virtual power plants".

II. Markets need to adapt as renewable energy takes a greater share, with new regulatory approaches and policies to ensure its long-term success

Markets need to innovate to meet the specific needs of renewable energy, but views vary on how quickly that should happen. Some experts see speed as essential to fostering growth; others urge caution, stressing the importance of continuity, and keeping the lights on.

Real-time power pricing in combination with smart meters and smart equipment enable market-based demand responses, and novel IT-based services for power producers, consumers, utilities, and businesses allow for a systemic transformation. Reverse auctions for new renewable power generation capacity can drive ever new lows in investment and operational cost.

New regulatory approaches and policies are needed to support new markets (and to improve existing markets) for power, capacity, storage and other grid services. Standards and quality assurance will be essential in emerging markets.

III. The relationship between information technology and renewable energy is essential, but the full scope of complementarities is yet to be fully understood

China has already installed 230 million smart meters, and many other countries are unrolling similarly ambitious schemes. The evolving nexus between information technology and the power sector will be a defining feature of the energy transformation, enabling for the first time a systems approach to power supply and demand, more sophisticated energy management systems, and adding the flexibility essential to integrating variable renewables.

But there is little certainty on how this will transpire in practice. Important questions remain regarding the optimal functionality and integration strategies for smart meters and smart appliances. New challenges, such as cybersecurity, are expected to emerge.

Innovation context: Low vs high variable renewable energy share

- **Low VRE:** Up to 15-25% share, no major integration problems. Requires some extra fossil fuel flexibility, more interconnectors.
- **High VRE:** 25%+ share, innovation requirement grows considerably. Many more interconnectors, demand-side management, sector coupling, storage/curtailment. With highly variable prices, low load hours in fossil plants, growing investment challenges, fundamental changes are needed to market structure.

IV. Electricity storage is integral to the renewable transformation, with diverse views on forms it will take

Electricity storage is a core feature of the renewable transformation, but expert opinion on its future diverges significantly. Grid-based batteries are growing fast, while home based batteries (which allow maximised self-consumption and autonomy) offer interesting innovation opportunities whose market potential is not yet well understood.

A massive uptake of electric vehicles offers the potential of significant battery storage capacity and new demand side flexibility, as well as growth in overall electricity demand. Thermal storage (eg ice) is also proving effective in shaving the peaks and filling the valleys of power demand, while spinning mass and pump storage (of water at altitude) still dominate energy systems for short-term and medium-term storage.

V. Innovation can be found at all scales, from micro-grids to continental super-grids, from rich to poor

Some of the most exciting innovations can be found in **mini and micro-grids**, which can bring access to modern energy for the first time to remote and underdeveloped communities. At the other end of the scale, **continental-scale 'super-grids'** are now envisioned, connecting time zones, hemispheres, and geographies with very different availabilities of renewable energies.

VI. Flexibility is key; context-relevant solutions essential

Flexibility is needed in policy design, as the end points will differ by country, and the pathways to get there will vary. Different innovation contexts shape options for technology and operational choices just as much as the availability of resources. Rapidly growing power systems can leapfrog, for example, through power systems design optimized for flexibility, while more mature markets will need to work with incumbents. In remote or island systems, the economics are favourable to rapid and ambitious change, but capacity is limited.

1 What is Innovation and why do we need an IRENA Innovation Week?

Innovation is a process of measurable and permanent real-life change that brings value added that did not exist before. It builds on invention and research, development and demonstration but the practical application is critical. Invention, innovation and the global transition towards renewable energy stimulate one another thus creating a virtuous cycle.

The urgency and magnitude of the energy and climate challenge, the decarbonisation of the global economy by the second half of the century, drives inventors and innovators to remarkable levels. Some of the innovations are disruptive: they accelerate the demise of fossil and nuclear energy and the centralised utility business models that thrive on these forms of energy. Other innovations are enablers to integrate more renewables into power systems. For example, they make it possible to provide modern energy to populations that could not be served by the old energy systems. Good policy and economic frameworks as well as international harmonisation, notably of standards, can stimulate the right kind of innovation and accelerate replication. Effective policy evaluation and learning is necessary to ensure this succeeds.

With its First IRENA Innovation Week on "The Age of Renewable Power" on 10 to 13 May 2016 in Bonn, Germany, the International Renewable Energy Agency (IRENA) provided a first-of-its-kind mapping of current innovation for the power sector, and explored the complex relationship among different kinds of innovation and how they depend on policy. IIW is based on the notion that innovation can be planned and it leverages the unique international network that IRENA provides. It showcased best practice, a key insight in a sector that is seeing in recent years more rapid change than in the previous century. It also charted the way forward towards a Global Innovation Agenda for international cooperation. The event was well attended with 238 participants from 41 countries and the success of the first innovation week has shown that this event fills an important gap and it can act as an anchor for the innovation work of the Agency.

A successful innovation dialogue requires interesting and diverse partners. IIW2016 has provided a global platform for thought leaders, technical experts and policy makers to share their vision. The Opening statement by BMWi State Secretary Rainer Baake set the scene, showcasing how Germany innovates through its Energiewende. The meeting has benefitted from cooperation with important partners including ABB, the German metrology institute (PTB), Siemens, the International Electrotechnical Commission (IEC), the European patent office (EPO), the European Organization for Nuclear Research (CERN); the German aerospace centre (DLR), E.ON, etc. These partners brought unique technical knowledge to the table that has greatly enriched the discussion. IIW brought together a diverse global audience of public and private sector experts to identify transition trends and innovations that will facilitate the transition;

A successful dialogue also requires a conducive environment. The facilities of Beethoven Halle in Bonn provided such environment though a generous functional setup, adequate technical facilities, good catering and a beautiful location with view on the Rhine river.

The event reception was hosted by the City of Bonn and the event included visits to various institutions in the region working on renewables innovation:

- The Federal Network Agency (German regulator);
- E.ON Energy Research Centre at the technical university in Aachen;
- Jülich Solar Institute (CSP test installation);
- German Aerospace Center: DLR's thermal storage laboratories in Cologne.

This allowed to showcase Bonn and its environment as a hub for renewable energy transition, an angle that so far has not yet received the attention it deserves. Highlighting this hub vision for the Bonn region is one of the innovations resulting from IIW2016.

The fact that the Innovation Week took place back-to-back with the UNFCCC SBSTA allowed climate experts to engage in a key energy discussion and the findings of IIW2016 have been put to good use in informing the climate discussions, one of the most pressing problems of our days.

It is clear that energy transition must be a corner stone of any climate solution and making that link and bringing these two different constituencies together is critical and IIW2016 has helped to do so through participants in both events as well as the fact that IIW2016 findings were presented during the UNFCCC Technology Expert Committee (TEC) sessions.

2 The Power Sector Innovation Space

The First IRENA Innovation Week provided **a map of the innovation space in three dimensions**:

- Realms of innovation (plenary sessions)
- Emerging solutions (deep dive sessions)
- The application context (group discussions)

Following breakout sessions summary sessions brought every one up to speed and allowed to mesh the three dimensions in an effort to identify innovation opportunities.

"Realms" of innovation, which were addressed in plenary discussions:

- **Technological innovation**, such as from material sciences, hardware and software, technical systems configurations or "architecture", smart grids and grid services, etc.;
- **Systemic innovation**, such as new business models, market design, regulation and policy instruments, institutional and policy frameworks, financial instruments, etc.
- **Operational innovation** in system operation and management that result from advances in ICT, including consumer engagement, supply side management, demand response and web-enabled "virtual power plants".

A variety of new technologies and energy sub-systems as well as management and policy approaches were discussed aiming to interconnect and advance in all three realms. These discussions were structured in **seven deep-dive sessions that highlighted emerging technology, operational and systemic solutions**:

- The future grid: Smart mini- and micro-grids;
- The future grid: Electric highways;
- Energy storage and electric vehicles;
- New market designs;
- Energy systems modelling and planning;
- Extending the frontiers of reliability;
- From science to innovation.

The plenary sessions were chaired by a policy maker with a good understanding of the needs of that specific constituency. Participants included a mix of representatives from public and private sector as well as academia.

Statements saying that there is a "need for disruptive thinking" or "innovation in our thinking" and "innovations in the narratives" express an understanding that innovation starts with new ways to think about and explain energy systems, how they work today and can work in future, and how they can evolve or be disrupted. For true innovation it is critical that such thoughts are ultimately translated into change “on the ground”.

Just as power systems structure and the availability of renewable energies vary widely, so does innovation in the sector, and when assessing the usefulness of innovation and its potential for replication, differences in technical systems, industry structures, regulatory frameworks, the dynamics of policy-making and public discourse need to be considered. The high level opening showcased country perspectives ranging from Costa Rica to Germany and Russia, and juxtaposed them with key technology perspective of key technology providers such as ABB.

The world is witnessing rapid change in power supply: Costa Rica produced 100% renewable power for 300 days in 2015, while Germany reached 33% overall during the year, and 88% for several hours during the day on 8 May 2016. Around the same time, Portugal had 100% renewable electricity for 4 consecutive days. The discussions throughout IIW also highlighted that Denmark is a leader in system integration in terms of sector coupling, flexible fossil. Exports can be a driver such as in the case of Russia with 50 GW wind project under consideration. And another important insight was the speed and dimension of change that is ongoing in China, a leader in power sector transformation with 230 million smart meters installed and plans for more than 22 UHVDC lines above 800 kV/13 GW by 2020. At the same time US cases for Hawaii and California showcase the importance of new market designs, business models and innovative policy frameworks that can supplement technology innovation.

"Application contexts" for innovation, depending on the state of development of energy systems. These were addressed in **three group discussions focusing on specific types of power systems**:

- Small isolated systems or grids on islands, remote locations, or in poor, predominantly rural areas, characterised by a lack of access to modern energy;
- Incomplete and newly evolving grids in emerging economies, characterised by high economic growth and rising energy demand;

- Mature and complete grids with old (or amortised) infrastructure in developed countries, characterised by low growth and excess capacity in some cases.

These application contexts shape the options for technology and operational choices just as much as the availability of renewable energy resources and options for interconnections that result from physical geography. Physical environmental conditions, such as high or low temperatures, high humidity, or high salinity also play a role.

3 IRENA Innovation Week Highlights

This section presents the key highlights from the Deep-Dive sessions and the Application Group sessions.

3.1 Emerging Solutions - Deep-Dive Sessions

Innovations in renewable power generation technologies were addressed throughout the programme. Seven issues were selected for detailed examination in the deep-dive:

- Smart Mini and micro grids, including access to modern energy in areas not yet served;
- Electric highways: Interconnections and the super-grid;
- Storage of energy and electric vehicles resulting in sector coupling;
- Modelling and planning of energy management and system development;
- Reliability and quality in the manufacturing of equipment and system management;
- New market designs for electricity, capacity, efficiency and demand response;
- Science-to-innovation process: from patents to tracking of innovation trends.

Table 1. Overview of deep dive session outcomes

<table>
<tr><th></th><th>EXCITING DEVELOPMENTS</th><th>IMPACTED CONSTITUENCIES</th><th>ROLE FOR INTERNATIONAL COOPERATION</th></tr>
<tr><td>(1) SMART MINI- AND MICRO-GRIDS</td><td>Virtual generators – Next Kraftwerk and Tiko already implemented this business model</td><td rowspan="7">• All stakeholders (energy planning ; reliability ; science-to-innovation)
• Mature power systems (market design ; smart grids ; electric highways ; science-to-innovation)
• Emerging power systems (market design ; electric highways)
• Utilities (smart grids ; storage & EVs ; electric highways)
• Technology, internet, mobile phone and commercial transport companies (storage & EVs ; market design)
• Rural villages and population in poor areas (smart grids)</td><td rowspan="7">• Creating common vision around the deep dive areas
• Best practice, knowledge and information sharing
• Development, utilization and harmonization of standards
• Cooperation of stakeholders among each other, e.g. TSOs, academia, industry/private sector, national stakeholders
• Integration of neighbouring markets, role of interconnections
• Reaching economies of scale, and ensuring interoperability of systems
• Combination of policies and instruments
• Innovation beyond technologies for policy, financing, business models
• Inform policy-makers (energy, electricity, climate, planning) and innovation initiatives (e.g. Mission Innovation)</td></tr>
<tr><td>(2) ELECTRIC HIGHWAYS</td><td>Gas insulated transmission lines (GIL)– extra-high voltage saving space in contrast to overhead lines</td></tr>
<tr><td>(3) ENERGY STORAGE & ELECTRIC VEHICLES</td><td>Mobility as energy service – electric vehicles enabling sector coupling</td></tr>
<tr><td>(4) NEW MARKET DESIGNS</td><td>ICT offers closer engagement of consumers and sensitization to price signals</td></tr>
<tr><td>(5) ENERGY SYSTEMS MODELLING & PLANNING</td><td>Increased computational capability – more comprehensive and reliable modelling including RE</td></tr>
<tr><td>(6) EXTENDING THE FRONTIERS OF RELIABILITY</td><td>Quality control & standardisation pave the way to bankability</td></tr>
<tr><td>(7) FROM SCIENCE TO INNOVATION</td><td>Evidence of step innovation trend on ICT focused to enable RE integration</td></tr>
</table>

Renewable Power Generation Technologies

A message which was repeated across different session of the IIW, was that the generation technologies needed to move forward with the transformation of the power sector in the next two decades already exist. From solar and wind power to ocean power technologies, the cost is coming down, while efficiency, reliability and durability are improving. This is a consequence of discoveries of new materials, new designs and technical configurations, imaginative uses of ICT-enabled "smart" technologies, new technologies and quality management system in manufacturing, and innovations in the management and maintenance of installations. Therefore the importance to reinforce efforts into the other realms of innovation; operational and systemic innovation.

3.1.1 The Future Grid: Smart Mini and Micro Grids

Mini and micro grids continue to be pursued as an alternative to access affordable, reliable, sustainable and modern energy for population not served with electricity yet. Furthermore, in areas with incomplete or unreliable grids, micro- and mini-grids are becoming a recognized embedded infrastructure within connected grids. In mature grids, the new possibilities and economics of micro- and mini-grids in combination with advances in energy storage, can reduce reliance on the existing distribution grid and result in grid defection. New independent grid cells can expand and be interconnected with one-another to become "federated" to form larger systems, or connected and become "nested" in existing grids, bridging the gap between mini- and large-grids. Developments discussed during the session included:

- The use of low-voltage direct current (LVDC) systems in mini-grids to avoid the inefficiencies of multiple power conversions as in large integrated grids.
- The emergence of pre-configured packages, which are suitable for and initially cover the typical basic needs of households (200W) or villages.
- New approaches to the control of micro-grids and devices connected to it, becoming a test bed for energy storage or demand response solutions to be deployed in future in large grids.
- Improvement in smart converters provide opportunities for additional grid services and communication among devices. These can enable and aggregate demand flexibility and an efficient dynamic behaviour of power generation, demand and storage over time.
- In distributed generation systems, the deployment of batteries with smart management systems can now act as "virtual generators" with high capacity and 1000s of cycles.
- Evolution of money transfer applications on mobile phones to allow business model innovation

3.1.2 Electric Highways: The Super-grid

Continental-scale transmission grids, or ‘super-grids’, are now envisioned due to ongoing advances and cost reduction in electricity transmission technologies. Super-grids would provide interconnectivity among different time zones, hemispheres, and geographies with very different availabilities of renewable energies. This would allow matching supply and demand, located geographically far away from each other 24 hours per day. Progress discussed in this area at the IIW included:

- Transmission lines with 1000 MW capacity at 320 kV are becoming routine, with some systems operating at even higher capacities and voltages.

- China plans for more than 22 ultra-high voltage direct current (UHVDC) lines above 800 kV, and added capacity of 13 GW, by 2020. This is part of the country efforts to lay the ground for a continental scale grid.
- Voltage source connectors (VSCs) of up to 1600 MW capacity enable high-capacity transmission using direct current (DC).
- Cables with mineral insulation are in service with capacities reaching 600 kV. Gas-insulated lines (GIL) are available up to 500 kV.
- Some participants also mentioned some reservations, as interconnectivity across countries can be costly and politically complicated to realise.

3.1.3 Electricity Storage and Electric Vehicles

In the public discussion, advances in battery technology take centre stage, especially in the context of electric mobility from e-bikes to electric vehicles, while spinning mass and pump storage (of water at altitude) still dominate energy systems for short-term and medium-term storage, respectively. Yet, there is a multitude of new and improving technologies and approaches to storing energy or electricity, including power-to-power (batteries), power-to-heat, power-to-gas and power-to-liquid (fuel), which provide many more options than traditional pump-storage. Although the overall market is still small, using battery storage at utility scale is proving able to provide cost-effective grid services in many locations. The growing market share of electric vehicles may become key in tacking climate change as the decarbonisation of power supply through renewable energies would result in the decarbonisation of the transport system. Some key points discussed at this session are:

- System integration are propelling batteries to expand their role in the management of energy systems from households and cars to utility scale battery storage to provide grid stability and supply security.
- Thermal storage – of heat and of cold (e.g. in the form of ice) – is proving effective in shaving the peaks and filling the valleys of power demand. This is an example of "sector coupling" and the efficiencies that can result, in this case by combining power, heating and cooling.
- As electric vehicles can store power, they can also provide grid services, especially frequency and voltage control to integrate variable renewable power in power grids. Electric vehicles charging times can be managed to alleviate grid stress, to "cut the peaks and fill the valleys".
- "Smart charging" might allow electric mobility to grow without creating a need for additional power generation capacity.

3.1.4 Modelling and Planning

Modelling and planning are essential for many aspects of energy system development, from long-term investment planning and siting decisions to short-run operational optimization. In order to manage the power sector transformation, bridging these time horizons in planning is becoming a key issue. The capabilities of various computer modelling tools to support operation and planning keep improving, allowing the tools to increase their granularity and better address uncertainties. Such improvements are enabled by more powerful computational capacity and application of efficient model application methods. Challenges still lie on bridging operational time scale and investment time scale. In particular, investment planning in generation and in transmission requires not only to reflect the long time horizon due to long project lead time, but also to reflect the conformity of national energy policy goals. Discussion from the four speakers highlighted the following aspects:

- From the developing partners' point of view, VRE planning is very relevant but there are only a few tools available that are suited to handle the new uncertainties associated with VRE. Development of a regularly updated master-plan based on scenario approach is important in giving guidance to private sector RE investments. Sets of scenarios covering uncertainties are necessary, and oversimplification in modelling needs to be avoided.
- DLR's REMix modelling tool combines long-term investment planning issues with short-term operation issues. Such approach provides a basis for science based policy advice to support policy decision making. The modelling results highlighted importance of flexibility of non-VRE part of the system in order to accommodate high share of VRE in a cost efficient manner.
- Siemens power system analysis tools for shorter term physical phenomena allows to assess VRE integration solutions such as grid extension, smart gird, storage and load management. Advances and cost reductions in computing enables energy system simulation and modelling tools supporting planning to manage the uncertainties even in real-time providing more information to improve operational planning.
- Renewable energy is describing regional expansion of transmission grid and this expansion requires long planning horizon over decades. E-Highway 2050 project identified key "non-regret" transmission investment strategies and grid enforcements are the most economical way to reach the European climate targets towards 2050. The necessary costs would be in the range of 100-400 billion euro.

3.1.5 Reliability and Quality

The growth and increasing development dynamics of renewable power and enabling technologies go hand in hand with two key aspects: cost reduction and reliability of technology and systems. In order to scale-up investment in RE to the magnitude needed for the transformation of the energy sector, stakeholders require low financial as well as technical risk. Technical standardisation and quality assurance schemes, including testing and certification, are key tools for the mitigation of technical risk. Relevant developments discussed in this field included:

- Implementing technical standards requires countries to develop a conformity assessment infrastructure, including testing, certification, inspection, accreditation and metrology capabilities.
- The emergence of global and harmonised standardization and quality control schemes for RE, as the International Electrotechnical Commission (IEC) standards and the IEC-RE conformity assessment systems for RE.
- Challenges in quality assurance for RE systems shifted from components to installation and O&M of systems.
- Country policies embracing technical standards and quality assurance as a pillar of a national RE strategy.
- White papers on deployment of renewable energy should include standards and quality assurance as an integral part of a national strategy.
- Harmonisation of RE standards continue to be a major challenge.
- Standardisation is necessary but it has to be flexible enough to give space for new technology development.

3.1.6 New Market Designs

The energy transformation requires and is driven by innovations in market designs, support for investment in renewable energy and enabling new business models. Some of these innovations provide for competition and new market players to emerge, while others tend to protect incumbent businesses as they slowly change their power mix. Historically, a very effective innovation was the introduction of feed-in-tariffs, effective in opening closed grids to new generators and stimulating new technologies by providing financial support. Auctions for new renewable capacities to be build is a recent innovation that resulted in the emergence of new market entrants and has revealed surprisingly low production costs for new renewable capacity. Some key issues highlighted during the session are:

- The need to open the markets to all players, including large and small.
- Renewable power should be considered as an active player in all existing and emerging markets.
- Market design and regulations should support investments in generation adequacy and system flexibility.
- Electricity markets are evolving to respond quickly. It was suggested that a minimum of 15 minutes to closure might be implemented.
- Countries should be clear that electricity markets have to be designed to support the energy transition and not hinder it.
- Participants stressed the need to remove all distortions currently present in electricity markets
- Net metering is a policy instrument that allows small scale RE generation to "use the grid for storage" of their own power.
- Suitable tariffs should be introduced where renewable energies gain higher shares of the power mix, in order to guarantee reliability of system, security of supply and fair distribution of costs among consumers.
- The cutting edge of market-stimulating innovation is retail tariff reform, moving from large blocks and long periods of stable prices and once-a-year meter readings towards real-time prices. They can apply to small generators (feeding into the grid) and power users (feeding off the grid).
- The evolution of smart meters in combination with remote meter reading and smart energy management systems is providing ever more possibilities for real-time pricing to stimulate flexibility in supply and demand, and the emergence of innovative additional services and new business models.
- Innovation-friendly regulatory frameworks and advances in ICT have paved the way for a new kind of aggregators of supply, demand, storage, and other grid services.
- For potentially millions of power producers and consumers within their system, aggregators can reduce transaction costs for market participation and provide additional services.
- Increased coordination and integration between neighbouring markets should be pursued

3.1.7 From science to innovation

While innovation depends on framework conditions, inventions and innovations can also influence the evolution of frameworks. The pathway of ideas from the laboratory to business practice is a key driver of renewable energy innovation. Impact is measured not on ideas but on innovations which have become commercial solutions accessible to the population that needs them. This session discussed how to support early stages of innovation, but also how to foster their transition to the market place. Some highlights from this session are:

- Patenting of inventions and innovations holds steady for renewable power generation technology. In the past 5 years, it has increased strongly for information and communication technology (ICT) and smart grid applications.
- Innovative schemes for tracking inventions, notably in ICT, focusing on climate mitigation, and computer-implemented inventions (CII) can support and accelerate the energy transformation.
- Recent analyses by the European Patent Office (EPO) have revealed a strong correlation between Innovation and patenting, and economic performance and trade.
- Open source innovation is another pathway, deployed by for example CERN.
- Support to entrepreneurship for innovations continues to be crucial.
- International cooperation on harmonization and standard-setting can help accelerate the diffusion of new technologies and operational approaches through international markets.
- 42% of all wind-energy related patents are held by only 5 companies. It was debate whether this type of indicator shows either maturity of a market or a potential effect that the positive impact of patented innovations is concentrated in developed regions only.

3.2 The Application Context – Group Discussions

Different types of energy systems, from small to emerging and established systems require innovative solutions to address their transformation towards a low-carbon and economically viable future. With the aim to address the nuance of innovative solutions for different energy systems, or application contexts, the IIW2016 held focused discussions for:

1. Small isolated systems or grids on islands, remote locations, or in poor, predominantly rural areas, characterised by a lack of access to modern energy;
2. Incomplete and newly evolving grids in emerging economies, characterised by high economic growth and rising energy demand;
3. Mature and complete grids with old (or amortised) infrastructure in developed countries, characterised by low growth and excess capacity in some cases.

3.2.1 Highlights from small isolated power systems

The group discussions highlighted that providing access to modern energy to the population without access continues to be the main challenge for this constituency. To address such a challenge, technology innovation is not enough. Significant efforts are needed in systemic innovation, particularly two aspects were stressed: financial mechanisms to implement renewable energy projects with high upfront costs in low-income communities, and new business models tailored to the context of communities living in small and remote population areas. Some of the key aspects underlined during the sessions are:

- Policies and regulations should facilitate private sector participation in the off-grid sector.
- Critical need to align objectives of governments and local utilities, especially in island contexts.
- New business models tailored to rural communities are needed and integration with technology platforms to reduce operational costs.
- Efforts are needed to build human capacity across the value chain, including operation & maintenance, and power system modelling and planning, tendering and procurement.

- Financing continues to be a major hurdle. Capital is increasingly available with dedicated funds for energy access being instituted, but delivering that capital to end-users (consumers and developers) requires customized financing instruments.
- Public financing can play an important role in de-risking investments and leveraging private financing into projects, thus facilitating a transition to a market-based approach to the development of off-grid renewable energy systems.
- There is a need to implement technical standards and quality control measures to ensure end-users and investors are receiving the service and return expected.
- More attention is needed on issues around technology adaptation. Aspects like: high temperature, high humidity, high salinity, are not always considered when adopting technologies developed in regions without such conditions.

3.2.2 Highlights from emerging and evolving power systems

The group on emerging power systems agreed that the energy sector transition by 2035, into a low-carbon sector, can be done with the state-of-the-art technologies available today. The priority issue is to innovate in system integration as well as systemic aspects to rapidly integrate these technologies in a very dynamic power sector. This will require innovations that enable a major scale-up in renewable power investments, long term and stable technical and political plans, and close coordination between all stakeholders involved in the energy sector. Concrete discussion points included:

- It was stressed that innovative technologies is needed for a low-carbon transition in the power sector, in the next two decades, have already been developed. Currently, the need is to focus on the effective use of these new technologies.
- Renewable power deployment must be linked to the socio-economic goals of the country. For example, grant energy access to the complete population, energy security, etc. Consequently, the short, mid and long term planning and polices for renewable power should be developed based on unified goals.
- In many countries there is a need for better and holistic mid-term planning, to complement long term plans.
- Large investments are needed in power infrastructure in emerging systems. However, it is not clear who should pay for grid investments: transmission system operators, distribution system operators, or other power system stakeholder.
- Public acceptance will continue to be critical. Therefore, stakeholder engagement and education of customers will be an important factor for a successful power sector transformation.
- It was highlighted the relevance of strengthening inter-ministerial and -organizational coordination to facilitate the transition process.
- Technology solutions need to be adapted for the specific national and regional context.
- A number of emerging economies still lag behind in developing and implementing technical standards and quality control measures for renewable energy systems. Power systems should be founded on sound technical standardization. Therefore the need to engage in international standardization processes and to implement such standards in quality control schemes for renewable power.
- The optimal mix of flexibility options differs by country -storage, markets mechanisms, curtailment, interconnectors etc. This aspect requires more attention and analysis at country level.

- System integration and sector coupling brings numerous benefits by materialising synergies; e.g. electric vehicles and grid balancing. However these aspects are still overlooked.
- It is critical to establish a credible long-term policy framework that provides stability beyond the policy cycles; e.g. need for enforcement through legislation.

3.2.3 Highlights from mature power systems

In the group discussions on developed and mature power systems, it was noted that, in contrast to emerging systems, major infrastructure investments might not be needed in the short-term. However, important issues included: how to better use the existing infrastructure and available flexibility options to boost the share of renewable power in these mature systems. Addressing this issue would require innovation in regulations, system operation, deployment of ICT as an enabler of renewable power, and more structured and target oriented exchange of experiences between countries. The following are some of the points underlined during the discussions:

- As the energy sector transformation progresses, new challenge appear:
    - How to use surplus RE electricity during an increasing number of days?
    - What are the needed market and policy reforms to integrate a high share of variable renewables at the optimal economic benefit?
    - Looking back, the projections 15 years ago significantly underestimated the innovation potential in the power sector. Are we making the same mistake for the next 15 years?
- It is time for stocktaking. There was a clear call to learn from front-runners; e.g. Denmark was mentioned as an innovation leader, which is well advanced in sector coupling and flexible coal
- Innovative business models still need to account for the new added value from renewable power. Adequately valuing aspects such as resilience and security could enable markets to provide their own innovative solutions
- More RE has gone hand in hand with higher reliability, supported by sound international standardization and quality control measures. It is recommended to strengthen the engagement in international standardisation and quality control for renewable energy, also as a platform for exchange on good practices.
- It was noted that grid investments might not be urgent for this constituency but necessary for the future
- There is no single solution to deal with flexibility issues
- Innovations will continue to appear as the systems are evolving. The highest RE shares are not necessarily in the systems with the broader portfolio of innovation but in the ones with more focused, targeted and stable innovation efforts.
- There is a need for a better coupling between ICT infrastructure and energy infrastructure
- Integrated markets require homogeneous regulatory frameworks
- Mature hydro may need a revisit of design issues; including broader functionality thinking: hydrology, flood control, irrigation, water usage.

4 Synthesis: Visions of the Age of Renewable Power

The IRENA Innovation Week, in highlighting many different types of innovation and their (potential) impact, helped clarify visions of the Age of Renewable Power. Innovations in technology, operations, energy systems and their institutional, regulatory and policy frameworks depend on one another, and play out differently depending on the status of energy system development, availability of renewable energies, geography, and political and business landscapes. The table below shows how the discussions at the IIW demonstrated that: innovation is equally relevant in technological, operational and systemic aspects, and solutions are of two natures, some are very locally specific for each application constituency and other are cross-cutting solution applicable to all constituencies.

Table 2. Innovations in the power sector for different types of power systems

	SMALL ISOLATED SYSTEMS	EMERGING SYSTEMS	MATURE SYSTEMS	CROSS-CUTTING
TECHNOLOGICAL INNOVATION	• Low voltage direct (LVDC) current systems • Modular plug and play systems • Virtual generators based on batteries and smart control systems	• New ultra high voltage transmission direct current (UHVDC) transmission lines • Voltage source connectors • Gas insulated lines (GIL)	• Stronger cross-border interconnections at high voltage direct current • Thermal storage to balance power supply and demand	• Electric vehicles as grid integration enabler • Batteries for grid services
OPERATIONAL INNOVATION	• Simplified planning and operation tools for small systems	• New grid layout with nested structure and integrated DSM	• Increased computational capacity to manage uncertainties in real-time	• Modelling tools combining long-term investment planning issues with short-term operation issues • Regional integration in long-term planning
SYSTEMIC INNOVATION	• Mobile payment model • Adaptation of innovative technologies to local climate and market conditions	• Innovative regulations to facilitate access of renewable power actors in growing power systems • Market design valuing additional services provided by renewable power • Financial instruments to mitigate risk and scale-up infrastructure investment	• Market design and regulations incorporating generation adequacy and system flexibility • Aggregators of supply, demand, storage, and other grid services • Smart metering	• Retail tariff reform from a once-a-year meter reading towards real-time prices • Engagement in international standardisation and implementation of quality control • Sectors coupling

Therefore, a variety of outcomes can be imagined in the form of visions for future energy systems in the Age of Renewable Power. They will be variants of a core concept, which may be described as follows:

Innovation in renewable energy technologies leads to a multitude of options to harvest natural flowing energies at reduced cost and improved quality, reliability, durability, and ease of use. This will result in a highly diverse renewable energy generation infrastructure. This diversity enables a portfolio effect that reduces risk and increases reliability and resilience of the system as a whole as well as its components.

Connecting the diverse power-generation equipment will be a smart grid. It has bi-directional flow capacity – power flows can be reversed almost instantaneously when needed – as well as digital signal-processing power throughout, either through the grid wires or through parallel ICT infrastructure. This smart grid will be a hybrid, combining elements of the semi-autonomous micro- and mini-grids and smart "behind the meter" home or business energy management systems it embeds, with elements of an equally smart high-capacity, high-voltage, long-distance transmission grid – or "super-grid"– allowing for the interconnection over large geographies, producing portfolio effects at regional or even continental scale. Depending on the current status of grid development, needs and choices, the balance of the "micro-grid" and the "super-grid" will vary among regions and countries, but practically all grids will combine both and thus be hybrid grids.

Discussions indicated that on-grid and off-grid solution will continue to be needed for the energy sector transformation, and support is needed for both options. Meeting the decarbonisation targets for the sector will not be achieve by large and centralised grid systems only, but renewables based mini-grids will be play a crucial role while also providing electricity to millions of people who still do not have access. Mini-grids should be implemented following standards that enable the different mini-grids to be connected to each other in the future.

With 100% renewable power, much of fluctuating, demand flexibility, storage, and interconnections help balance supply and demand throughout the grid, second by second. They will compete: The more demand is flexible, the less storage or interconnection is needed; the more storage is available, the less demand flexibility and interconnection is required; and the more geographies are interconnected, the less storage needs to be build and demand be flexible. Again, the balance of demand flexibility, storage, and interconnection will vary among regions and countries, but most systems will have all three. Only isolated or island grids may not have a practicable option for interconnection, and will thus need to rely on demand flexibility and storage, as well as flexible conventional generation units.

In all such systems, strong economic incentives are needed to ensure that power generators, users, operators of storage systems, and aggregators act so that the grid is not only stable, with supply and demand in balance, but that all the components connected to the grid behave to make the whole system dynamically efficient. This will require innovations in market structures, tariff designs and component price formation in most countries, regions, and grids. Essentially, the balance of supply and demand on the grid, the grid load, needs to be reflected in real-time changes in prices, so that all grid-connected participants in the power market can adjust. The cost of achieving such a smart and self-regulating system is investment in digital infrastructure, the benefit is the dynamically efficient behaviour of the whole, which reduces capital needs, energy wastage, and overall cost. Also the allocation of cost needs attention. For example, massive growth of self-consumption or even grid defection can disrupt the business model of distribution utilities recovering system costs from prices for energy delivered.

With renewable power costs reaching parity with fossil and nuclear power in ever more situations, and the promise of further rapid cost reductions, renewable power will win market share from fossil and nuclear power and eventually push them out of the market. This is happening in the power sector, and it will be repeated in other sectors, first in transport where electric vehicles promise to bring about many disruptive innovations in that sector, and then in heating applications.

The new energy system of the Age of Renewable Power will be cheaper to build and to run, and the social, environmental and legacy costs lower than the centralised and inflexible fossil and nuclear energy system it replaces. This is a consequence of falling component costs for all renewable power generation technology and storage technologies, the use of cost-free environmental flow energy (as free goods) instead of privately appropriated stocks of energy commodities, and the fact that renewable energies do not have the large social, health, climate, environmental and long-term waste storage costs of fossil and nuclear power.

Smart-grid technologies, when coupled with undistorted price signals reflecting renewable power supply and demand much in the way of current balancing markets, enable demand response, and stimulate grid-friendly behaviour of renewable power generators and operators of energy storage systems. They allow to go beyond maximizing the efficiency of individual energy system components and optimize the management of the entire system over time. This "dynamic efficiency" of the whole further reduces the total cost of the future energy systems.

This cost reduction can have disruptive effects, some of them welcome, others controversial. With lower capital cost, the opportunities for capital formation and deployment are reduced. With lower energy prices as well as higher levels of self-supply, and without the need for the long-distance trade and transport of (fossil) energy commodities, taxable economic activity and trade volume will diminish. This reduces tax revenue as well as gross domestic product, in spite of higher levels of energy services in terms of volume (kWh), quality, reliability, resilience, security etc. These disruptions will themselves stimulate innovation, and should thus be welcomed overall.

However, the transformation may also leave (un-amortized) capital assets stranded, and some learned skills obsolete. The bursting of the financial bubble around fossil and nuclear energy is underway, with bankruptcies in the coal industry, and significant reductions in the market capitalisations of other fossil-energy companies and utilities. A further "slow implosion" of the sector is now anticipated and prepared for. Regulators of financial markets, for instance, demand better disclosure of "climate-related risks" as a way to protect investors, the integrity of financial regulation, and the stability of financial markets. In spite of progress made, there may be need to understand better the impact of an accelerating transformation of the energy systems as well as related sectors such as the automobile industry, on the need for training and re-training of employees.

5 Towards an International Innovation Agenda for Power Sector Transformation

IIW2016 had high acceptance, as witnessed by the level and breadth of participation, feedback of those that participated and press coverage (Annex I). The important findings of IIW2016 have been showcased for members and a wider audience. A few such occasions included:

- The UNFCCC Technology Mechanism Subsidiary Body sessions in Bonn on 19 May 2016, where IIW findings were presented.
- Following the 11th council, "Innovation Day" was held in Abu Dhabi on 26 May where around 45 country representatives participated. IIW2016 outcomes were discussed and the participants provided valuable guidance on not only how to take the findings to the next stage but also how to build upon the experiences in focusing and structuring future energy weeks.
- Results of IIW will be tabled for consideration at Mission Innovation.
- IIW insights will be used for the preparation of IRENA Innovation landscape report, due early 2017. The report will benefit from a selected number of IIW2016 participants, who will join the advisory body.
- This IIW conference report will be distributed widely.
- Video material prepared during IIW including plenary session recordings and summary statements are available online. Slides and session summaries are available from the IIW webpage.
- A post-event webinar will be organized in order to inform the broader public.

Purpose of this effort is to ensure that findings result in accelerated innovation in practice.

This Innovation Agenda is at present and will continue to be reflected in IRENA's work programme, which includes Technology Briefs, Technology Innovation Outlooks, the forthcoming Innovation Landscape Report and, subject to the availability of funds, the next IRENA Innovation Week in summer 2017. IRENA will cooperate among others with the Mission Innovation, the Breakthrough Coalition, the Climate Technology Centre and Network (CTCN) and other emerging initiatives that were highlighted during IIW2016.

IIW2016 and the subsequent innovation day concluded that IRENA can play a key role in assisting countries, regions and utilities in their transition to the Age of Renewable Power, notably through:

- The development of a taxonomy of power systems for solution finding.
- Understand not only problems in integrating renewables in power systems, but also focus on the provision of solutions to address thereof.
- Providing a platform for the exchange of stakeholders' best and worst practice experiences.
- Convening different parties on a global and national level.
- Facilitating the sharing of information on implementation, targets and objectives, tariff options, financing mechanisms including (where needed) subsidies and business models to name a few.
- Supporting the efforts of international harmonisation of policies and regulators approaches, terminology, data and reporting formats, grid codes and standards.

- Assist in RE standards and metrics adaptation to national conditions.
- Working with commercial banks on technical and social aspects. Provide guidance on minimum requirements for RE projects.
- Developing good practices guides for practitioners, installers of various renewable energy systems, and financial institutions as investors in the sector on minimum requirement for projects as well as environmental and social aspects.
- Facilitating international cooperation to increase systems and markets in view of attaining economies of scale.
- Strengthening the work on system innovation, notably business models, and regulatory and policy frameworks;
- Focusing more on demand-side innovation for the integration of variable renewable energies, including smart equipment and thermal storage;
- Expanding work on grid services (e.g. stability, resilience, security) provided by renewable energy and storage systems, identifying value propositions and viable business models in view of accelerating their take up;
- Focusing more on seasonal issues and sector coupling opportunities that gain importance as the shares of variable renewable power rise. Focusing on seasonal variations of renewable energy supply and power demand, and their accommodation in energy system management. Developing work on sector coupling and the potential for co-transformation of the power, transport, and heating systems, as well as electricity and gas supply systems.

6 Outlook: the second edition of IRENA innovation week

IRENA Innovation Week 2016 has provided a map of renewable energy technology innovations and their applications, trends and future needs. It highlighted the need for market designs, regulation and policy to enable further innovation and rapid diffusion of good practice. It allowed for the consideration of renewable energies, energy efficiency, smart grids and storage, including the inter-linkages among them, as one unified innovations space that needs to be shaped by policy and international cooperation. The IRENA Innovation Week is a proven platform for advancing innovation for the Age of Renewable Power.

Participants supported the continuation of the IIW in the future and suggested that the IIW should be organised every year, based on the availability of resources. Concerning the location for the IIW, it was recognised that Bonn is a convenient location However, as alternative idea, it was suggested that the location could also alternate between Bonn and a location in a developing country. In order to ensure a direct link to the IRENA work programme, the Innovation Day was organised back to back with Council meetings following IIW. Furthermore, use national member country conferences would be used as platforms for IIW outreach and networking.

Recommendations on focus sectors included sector coupling, systemic innovation, innovation to achieve SDGs (energy access), and innovative finance. Following which, increased involvement of TSOs and regulators, as well as law-makers, should be explored in future IIWs.

Engagement of both public and private sector creates important value added. It was a truly global event that allowed comparison of experiences and identification of best practice across a wide range of situations and approaches. The deep dive sessions proved to be especially popular but it was critical to complement them with cross-cutting group sessions to find synergies.

For the next edition, provisions and platforms for even more dialogue would be beneficial.

As a next step, the practical experience will be evaluated internally and the findings will inform the preparations for the next edition.

Annex I – IRENA Innovation Week Outreach

Web site
All the material from the IRENA Innovation Week 2016, including this summary report, programme, and slides from presentations, are available at:
http://irena.org/innovationweek2016/

Participation
238 participants from 41 countries attended the inaugural edition of IRENA Innovation Week. This also signified the importance of Bonn and the region as renewable energy hub of global significance, operating at the nexus of energy and climate.

IRENA Innovation Week 2016 - Summary of Participation

	Number of Participants
Attended	**238**
Participants	107
Secretariats	31
Speakers	67
Students	33

The plenary sessions were streamed via IRENA's Youtube page. This drew in a significant number of viewers.

Press coverage
- The #IRENAinnovation hashtag was used by 660+ contributors in 1,200+ tweets over an 11 day period. In total, it reached 1.3+ million accounts and created 8.6+ million impressions.
- 30 social media cards were created for event speakers and shared throughout the event by both IRENA and our partners: https://www.flickr.com/photos/irenaimages/albums/72157667805018925
- The event recap video is available on an Innovation Week playlist on IRENA's YouTube: https://www.youtube.com/watch?v=tytP7nCSoRQ&list=PLGZxC2iViPRqtNBlNgYQA_fyTLD4GWytn
- Edited/branded plenary session video recordings and individual participant video interviews (10+) will be added to the YouTube playlist this week.
- The IRENA Innovation Flickr album has photos from all portions of the event: https://www.flickr.com/photos/irenaimages/albums/72157667805018925
- 5 IRENA newsroom posts were published on various elements of the event, and one more recap post will be published when the final report is completed: https://irenanewsroom.org/
- There were six media articles covering elements of the event