

Identifying challenges for achieving 100% renewable power systems by mid-century

Minutes of the online workshop of 6th June 2019, 16:00 (GMT+2)

I. Context

IRENA has invited leading member countries to join a programme of discussions and networking events for the international exchange of perspectives, plans and good practices in working towards very high levels of renewable power that takes place in 2019. The focus of this experience-sharing programme on innovative solutions for very high shares of renewable power by mid-century is on countries that have pledged very ambitious renewable power targets and nations that are already operating power systems with very large shares of renewable sources. Engagement in the programme and discussions are meant to provide valuable opportunities to learn from experiences, challenges and best practices of like-minded countries with respect to innovations that can help integrate a larger share of variable renewable sources into the power systems.

Activities benefit from financial support from the government of Sweden and are being organised in collaboration with the government of Uruguay.

The first activity of this programme took place on the 6th June 2019 in the form of an interactive online workshop. The focus was placed on the sharing of national objectives for renewable power and on the identification of expected, as well as experienced **challenges regarding the adoption of technology-driven innovative solutions for the accelerated deployment of very high shares of renewable power by mid-century**. This document summarises in chronological order the key points and highlights from this activity.

The speakers were the following:

- Paul Durrant – Programme Officer, Renewable Energy Innovation (IRENA)
- Arina Anisie – Associate Programme Officer, Renewable Energy Innovation (IRENA)
- Elena Ocenic – Programme Officer, Innovation Networks (IRENA)
- Truls Borgström – Deputy Director, Energy Division, Ministry of Infrastructure (Sweden)
- Hanna Ek-Fälth – Renewable Energy Analyst, Swedish Energy Agency (Sweden)
- Wilson Sierra – Manager of the Renewable Energies Department, Ministry of Industry, Energy and Mining (Uruguay)
- Rolando Castro Córdoba – Viceminister of Energy, Ministry of Environment and Energy (Costa Rica)

- Bilun Müller – Deputy Head of Unit International cooperation on energy, Federal Ministry for Economic Affairs and Energy (Germany)
- Hugo Lucas Porta, Head of the Regulatory Frameworks and Corporate Strategy, Institute for Energy Diversification and Energy Saving, Ministry for Ecological Transition (Spain)

II. Minutes of the discussions

1. Opening of the meeting and welcome speech: Mr Paul Durrant (IRENA), Mr Truls Borgström (Sweden), Ms Elena Ocenic (IRENA)

Mr Paul Durrant welcomed the participants and explained the rationale behind the series of networking activities. Mr Durrant highlighted the focus on informal exchanges between like-minded countries, both striving towards or already operating power systems with high shares of renewables and especially variable renewables. This international exchange of experiences begins with this online workshop and is expected to continue in different fora in the following months. Insights gained during these activities may be used for future publications, but IRENA will consult participants before doing so.

Mr Truls Borgström from Sweden's Infrastructure Ministry thanked IRENA for organizing the talk and provided background information on the rationale of why Sweden took the initiative to collaborate with IRENA on innovation for 100% renewable power. As there is a strong and broad political agreement in Sweden to achieve 0 greenhouse gas emissions and renewable power targets, the country is very interested in identifying best practices and innovation for a smart, cost-effective transition towards 100% renewable power. Moving towards 100% renewable power is clearly, also from a '*Nordic perspective*', a great challenge. Therefore, Sweden is hoping to pursue fruitful discussions and learn from other countries targeting similar ambitions.

Ms Elena Ocenic provided additional context on IRENA's activities across different workstreams in the realm of 100% renewable power and 100% renewable energy. The focus of this workshop and the following activities will be on **innovations and innovative solutions to achieve 100% renewable power systems**. Ms Ocenic also provided further information on how IRENA's member states have been selected to participate in the programme as well as on future activities planned. For this first discussion, the online workshop targeted mid-level officials, as well as experts who have a role in advising officials from countries that have similar policy ambitions in terms of decarbonizing the power system in the next two or three decades. Participating countries share certain similarities in the power system and face comparable challenges in reaching their renewable power objectives. Participation included representatives from countries that have policy targets to achieve between 80%-100% renewable power by 2030, 2040 or 2050, in addition to Uruguay, given it is a frontrunner in the operation of a power system with very high shares of renewable power with 98% of its power generated in 2017 from renewable energy sources.

2. Setting the scene: The systemic innovation approach proposed by IRENA in the Innovation Landscape Report – Ms Arina Anisie (IRENA)

Ms Arina Anisie introduced IRENA’s analytical work on solutions for flexible renewable powered systems and in particular IRENA’s recent *Innovation Landscape for Renewable-Powered Future* report. Thanks to tremendous cost reductions, wind and solar photovoltaic (PV) technologies are at the core of the clean energy transition. Shares of wind and solar in electricity systems need to increase in order to meet the Paris Agreement, nonetheless, their variability makes this a challenging task – hence the need for innovations to unlock flexibility and enable the cost-effective use of renewables. Currently, we are witnessing three innovation trends. These are:

- 1) **Decentralisation** with the growing deployment of distributed energy resources, which turn the consumer into an active ‘prosumer’ and fosters demand-side management;
- 2) **Digitalisation** with increasing Information and Communication Technologies (ICT), such as Blockchain and Internet of Things, entering the power sector which enable, inter alia, faster response, better management of assets and data collection;
- 3) **Electrification** of end-use sectors in order to prevent curtailment whilst decarbonizing sectors such as transport and industry.

From traditional power systems, in which flexibility has been only provided from the supply side, innovations today can unlock flexibility across the entire power system value chain, especially on the demand-side, but also across the entire grid.

The *Innovation Landscape Report* identifies the 30 most significant innovations in the power sector to increase flexibility to enable the integration of higher shares of variable renewable energy. Innovations have been identified in all dimensions, including market design, system operation and business models and enabling technologies. Ms Anisie highlighted the fact that innovations do not emerge in isolation and we need synergies amongst these to create impactful solutions. The report provides 11 examples of such solutions which combine innovations from different dimensions.

The report is available for free on the IRENA website:

<https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future>.

Following Ms Anisie’s presentation, Mr Truls Borgström from Sweden highlighted that electrification is an important topic in Sweden at the moment and that there is an increasing debate how to electrify transport and industry the smartest way. Ms Anisie outlined IRENA’s approach to electrification, which is promoting decarbonization and an increased use of renewable power. A recent publication which is highly relevant in this context is IRENA’s new **Innovation Outlook on Smart Charging for Electric Vehicles** to unlock synergies between clean transport and low-carbon electricity.

This in-depth study is also available here:

<https://www.irena.org/publications/2019/May/Innovation-Outlook-Smart-Charging>

3. Country presentations on challenges in the adoption of a systemic innovation approach as a key enabler to achieve high shares of renewable power by mid-century:

A) Sweden

Overview and current actions

Ms Hanna Ek-Fälth from the Swedish Energy Agency started the presentation by providing an overview on the current electricity production in Sweden and the rapid increase of renewables' share in the power system in the past years. Nuclear power assets are further reaching end of life and must be replaced. The 100% renewable power target by 2040, however, does not imply a 'stop date' for nuclear, but rather the expectation that the increasing competitiveness of renewable sources will crowd out nuclear capacity.

In order to expand renewables in electricity generation, Sweden implemented in 2003 the market-based Electricity Certificate System and a common market has been created with Norway in 2012. Furthermore, Sweden has already reached the 2020 renewable power target and the 2030 target of an additional 18 TWh of renewable electricity is forecasted to be reached as early as 2021-2022. Simultaneously, Sweden continuously supports research and innovation, whilst having a carbon tax as well as various support schemes and subsidies for solar PV and storage systems in place.

Challenges

Being part of the Nordic power system, Sweden and other Nordic countries experience similar challenges, especially in the realm of frequency stability. Sweden however needs to replace around 100 TWh from power units reaching end of their economic life which increases the risk of local shortage in grid capacity. The country is further witnessing a significant trend of electrification, especially in sectors such as transport and the steel industry targeting the development of hydrogen. This implies both significant changes and increases in electricity demand but may also offer immense opportunities for more flexibility in the power system.

Other significant challenges that Ms Ek-Fälth talked us through, include the cost-effective expansion of transmission networks, the substantial expansion of wind power which led to the formulation of a national wind power strategy and the need for electricity market improvements to handle flexibility issues. Ms Ek-Fälth finished on a positive note that Sweden has good preconditions to face these emerging challenges associated with growing shares of renewables in power systems and is adopting a forward-thinking approach.

B) Uruguay

Overview and current actions

Mr Wilson Sierra started his presentation by providing a detailed overview of Uruguay. Although being one of the smallest countries in South America, Uruguay is endowed with an abundance of natural resources, that are key in the clean energy transition. The country further places a strong focus on economic-, social- and environmental sustainability as well as on equitable distribution with human rights being of utmost importance on the agenda.

In 2017, 98% of electricity produced in Uruguay has been generated from renewable energy sources. This engendered the country's shift from being an energy importer to becoming an energy exporter and has been enabled not with the use of subsidies but through competitive auctions.

The transition towards clean energy is at the heart of Uruguay's long-term energy policy and has been endorsed by all political parties, which exemplifies the country's strong commitment to renewable energy. Uruguay further adopts a highly multidisciplinary approach to account for ethical, social, economic and technical dimensions and engages civil society, academia, financial institutions and state-owned utilities to successfully enable this transition.

Challenges

A key challenge Uruguay is facing today is the efficient management of energy surpluses as these amount to around 2 TWh per year, which equates roughly to a half of the country's yearly residential energy consumption. Other challenges entail developing effective measures on the demand side and the optimization of generation from existing natural resources to make use of the annual intra-day complementarity between hydro-, wind- and solar resources.

Uruguay's top priority for the future remains decarbonizing the economy. Similar to Sweden, Uruguay wants to electrify end-use sectors and is strongly focusing on mobility but also industry and heating to reduce oil consumption. On the transport side, Uruguay has already deployed electric vehicles, but the country is also considering green hydrogen, especially for long-distance buses and trucks. Mr Sierra further highlighted this energy vector's potential in decarbonizing other end-use sector, which is why power-to-X is also considered in other applications, including food and chemicals.

Mr Sierra also concluded his presentation on the optimistic note that positive results from the clean energy transition can already be perceived in Uruguay and the nation's energy sector is in condition to face future complex challenges.

C) Costa Rica

Overview and current actions

Mr Rolando Castro Córdoba started his presentation by highlighting that countries operating close to 100% renewable power grids face new challenges and that there is great value in exchanging information and learning from each other.

Mr Castro Córdoba introduced Costa Rica as fairly similar to Uruguay, although the country is larger in population size and smaller in territory. However, exactly as in Uruguay, there is no oil or mining but there is an abundance of natural resources for clean energy. In fact, the focus and development of renewable energy sources in Costa Rica's started as early as in the 1940's. The nation went against the World Bank's recommendation in the 1960's to place an emphasis on fossil fuels. Costa Rica first started focusing on hydropower, on geothermal energy in the 1980's before drawing the attention to wind power and more variable sources from the 1990's onwards. Currently, Costa Rica is also exploring other alternatives, including ocean power, hydrogen and biofuels. The President of Costa Rica has also launched a decarbonization plan in February 2019, targeting an entire decarbonization of the economy by 2050.

Challenges

Costa Rica has identified the transport system as the main challenge although achieving greater levels of competitiveness and efficiency in the electric sector are also of utmost importance. The grid's overcapacity particularly offers opportunities to electrify and decarbonize the transport and industry sectors. Optimisation is key in Costa Rica, especially in the realm of planning and dispatch as the country is promoting and experiencing an expansion in distributed generation, which however induces challenges in the power system.

Demand did not grow in the past years and Costa Rica's industry is changing and shifting towards a service-based economy. Because of the stagnating power demand, Costa Rica is planning to integrate more solar and wind rather than hydropower in the system. This has been also included in their 2018-2034 plan for additional power capacity. While this means that wind, and to some extent solar, will be key in the future power system configuration, Costa Rica will have to focus on reducing the risks and effects on the grid associated with their variability. As the nation is extremely vulnerable to climate change because of its location in the tropics, successfully addressing challenges on system resilience has been further identified as crucial.

Mr Castro also highlighted the fact that although a lot of funding is available and committed towards the energy transition from a generation side, there is funding gap for measures targeting demand side management and the decarbonization of end-use sectors. This is a paradoxical situation as the same goals are trying to be achieved.

On Uruguay's question on the role assigned to storage in the Costa Rican power system, Mr Castro stated that storage is, already today, key in managing renewables' variability. Hydrogen has been

identified as a key storage solution in the future and a few plans targeting hydrogen development have been instigated. Finally, although hydropower remains Costa Rica's 'main' battery, other solutions, especially second-use batteries from electric vehicles are also considered, especially in order to avoid disposal and extend the batteries' life.

Following Sweden's question on interconnections, Mr Castro stated that Costa Rica is part of an interconnected Central American system which expands from Guatemala to Panama. El Salvador, Guatemala and Honduras are the main electricity importers from Costa Rica and there are also some exchanges with Panama. However, interconnections are expected to rather serve for back-up electricity. In Nicaragua, the transnational lines are used for the domestic transportation of electricity, which creates congestion and impacts Costa Rica as their electricity exports cannot reach Salvador and Honduras. Nicaragua has not solved these issues yet.

D) Germany

Overview and current actions

Ms Bilun Müller commenced her presentation by providing a detailed overview of the current renewable power landscape in Germany. At present, almost 40% of electricity stems from renewable sources and there is a strong reliance on variable renewable energy sources, including wind and solar, rather than on hydropower. In the Eastern part of Germany for instance, wind generates sometimes over 50% of the electricity in the region.

Currently, Germany is already overachieving the 2020 goal to integrate 35% of renewable energy in the power system. The future goals for 2030 and 2050 are integrating 65% and 80% of renewable sources respectively. Ms Müller reinforced that this will certainly not be an easy task, but that Germany is on a good path to face future complex challenges.

Challenges

Ms Müller categorized focus areas and challenges Germany's power sector is facing in five distinct topics, which can be grouped into grid and electronics, storage, electrification, power-to-x and power-to-gas and research support.

In the realm of grid operation, the harmonization of electricity demand and generation over great distances throughout the year is a significant challenge in Germany: a lot of electricity, especially wind power, is produced in the North, but the highest consumption and the biggest users are located in the South of the country.

Ms Müller also highlighted the importance of tackling social acceptance in the energy transition and the challenge of securing citizens' acceptance to operate when building and expanding transmission lines.

Germany also wants to significantly boost storage facilities as the nation does not have as significant amount of pumped hydro storage as in other countries. Hence Germany has highlighted that the costs of Li-ion batteries are decreasing at such rapid pace and is working on developing materials that are less expensive and with a higher energy density.

Ms Müller underlined the increasing importance of sector coupling and making the best use of renewable energy to electrify end-use sectors, including heating, industry, transport and agriculture. There is strong government support for heat pumps and solar thermal to use solar power directly in buildings for heating purposes. Hydrogen is another focus area with projects i.a. targeting the production of ammonia. Producing chemicals from renewable energy and power-to-X and power-to-gas applications has been also characterised by Ms Müller as innovations of growing importance.

Germany is strongly supporting research, especially in the realm of solar PV where both higher efficiency rates, especially for crystalline silicone cells, and simultaneous price reductions are expected. Recycling solar cells is also an active area of research.

In order to face future challenges and further boost renewable power, Germany has identified the need for regulatory innovation and is currently preparing regulations for an auctioning system for a wide variety of innovations. This auction is not meant for innovative technologies but targets as a starting point innovation in pricing to foster competition. There is also increasing focus on technical innovations such a combination of different renewable energy technologies in one auction (e.g. hybrid systems).

Germany furthermore places a strong emphasis on solutions combining renewable energy with storage but also on empowering consumers to help increase power system flexibility via demand side measures. This is also why changing regulation to make it easier for prosumers to link their microgeneration to the main grid is becoming a priority.

Ms Müller concluded her very detailed analysis by summarising the most important areas that Germany has identified to date, which are storage, flexibility and sector coupling.

E) Spain

Overview and current actions

Mr Hugo Lucas Porta provided a thorough overview of the workings of Spain's electricity sector. In 2017, the share of renewables in power production amounted to 32%, with 20% coming from variable sources (17% wind and 3% solar). Spain has several enabling measures in place to integrate variable sources in their power system. These include, but are not limited to, the requirement that renewable energy facilities over 10MW have to be connected to two control centres whilst being mandated to forecast generation one day ahead. In 2003, the first operational procedures have been implemented for wind turbines to respond to disturbances on the grid,

operational procedures are keeping updated continuously. Additionally, the transmission system operator runs automatically the GEMAS prediction model in order to identify congestion.

Spain is currently working on the Integrated National Energy and Climate Plan 2020-2030, which will be submitted at end of this year to the European Commission. A noteworthy goal is the target of 100% renewable power and energy by 2050. In order to meet their interim 2030 goal of 74% renewable power, increases in variable renewable sources are needed: wind capacity needs to be doubled and solar capacity has to be multiplied by nine in order to achieve the target. Simultaneously, installed capacity of pumped storage also needs to be doubled and 2.5 GW of Li-ion batteries need to be integrated as well. It is further expected that from 2025, the combination of solar PV with batteries will be the cheapest option and will be hence the first power source to be dispatched. Concentrated Solar Power (CSP) capacity will also have to rise by 5GW and coupled with 9 hours of molten salt storage.

Challenges

Mr Hugo Lucas Porta highlighted the need for more visibility on power sector issues at distribution level, at national and European level, as most countries are and will be facing similar sets of challenges and mandated to work under the same rules set by the European Directive on the internal market for electricity.

On a national level, Spain will need more interconnections with neighbouring countries, especially with France. This calls for a well-designed transmission system plan. In the future, the key challenge in 2030 and 2050 will not be managing daily variabilities but rather enabling seasonal storage. Mr Lucas Porta mentioned on that point the previous presentations and the possibility of using curtailed electricity for hydrogen production or power-to-X applications, to be used as energy carriers for seasonal storage. This is furthermore discussed in Spain's 2050 decarbonisation strategy.

Mr Lucas Porta also highlighted the fact that many locations with high levels of wind generation are also suitable for solar deployment. As wind and solar display complimentary patterns, which may therefore enable more stable generation, hybrid power plants will be key in the future and are expected to have to lowest LCOE by 2030. Nonetheless, there are currently permitting, administrative and regulatory hurdles regarding their deployment.

Currently, mechanisms are also being foreseen and developed to target '*cannibalism*' and variable renewable's 0 marginal cost in order to secure power plants' internal rate of return. Mr Lucas Porta further mentioned that in future scenarios for Spain's power system by 2030, depending on the combination between wind and solar, there are times of the year where up to 30% curtailment of variable electricity may be experienced. This why opportunities in the realm of demand management as well as hydrogen need to be unlocked.

Other significant and noteworthy challenges include environmental as well as societal challenges associated with the rapid and massive deployment of renewable power plants, with both natural protection and social acceptance becoming increasingly important issues.

Mr Hugo Lucas Porta concluded his detailed presentation with Spain's long-term priorities regarding the power sector transition. These include the full decarbonisation of the Spanish economy, where no CCS is needed but rather, to some extent, gas produced from renewable sources. Successfully addressing seasonal variability, especially through sector coupling, is also a key priority. Mr Lucas Porta placed emphasis on the fact that, we need focus on measures as well as changes that go beyond the power sector. Moving forwards, behavioural changes and new patterns of consumption will be of utmost importance. At the same time, it is essential to harness opportunities from digitalisation and new business models, such as aggregators, whilst devising market designs for the creation of local electricity markets.

4. Discussion and identified overarching challenges

- **Systemic innovation approach:** A systemic approach was considered throughout the presentations of the participating countries. Most of the innovations discussed referred to enabling technologies, i.e. innovations that play a key role in facilitating the integration of variable renewable energy in the system but innovations in business models were underlines as well, which highlight that IRENA's recently published *Innovation Landscape Report* is relevant and timely. Innovations for generation technologies were mentioned as well, such as hybridization of power plants (i.e. combining wind, solar power plants and/or batteries).
- **Societal changes and circular economy:** There is a need to adopt a forward-thinking approach and to "*think even bigger*", i.e. to think about what kind of world or society we want to live in by 2050. For example, the '*sharing economy*' could lead to important efficiencies and perhaps even less energy demand, such as oil and gas for private transportation. It was agreed that **mobility** will be shared in the future and that the decision between the two current models ("*car-to-go*" versus public transport) could be a societal decision. A question was raised whether the shift towards a shared economy follows a *bottom-up* or *top-down* approach, i.e. whether policies are prohibiting/creating a legal/regulatory framework to create incentives or whether it will be the private consumers that will drive this change with '*good behaviour*'. It was acknowledged that such debates will depend on the perspective taken and the pressure form the industry. As such, consumers (and citizens) more widely will play an important role, which calls for behavioural changes and new patterns of consumption.

- **Electrification of end-use sectors:** Several countries talked about the importance of electric transport and electrification of end uses as a way to achieve a greater participation of renewables in the energy mix.
- **Power-to-hydrogen:** Interest in hydrogen was expressed by all participants but for different reasons and with different applications, ranging from seasonal storage to avoiding renewable curtailment to decarbonizing other sectors. A question was raised on whether there are pilot projects and demonstrations or whether hydrogen is considered in long-term scenarios. In the case of Spain, the demonstration projects are using hydrogen for the municipal bus fleet on Islands, which is cost-efficient thanks to cheap electricity from solar PV combined with grants for the extra cost of the buses, which translates into breakeven costs with the conventional buses (today already). In the case of Sweden, hydrogen is used to decarbonize the steel industry with the goal of decarbonizing the industry by 2035. Over the 2016-2017 period pre-studies were conducted, which are now materializing into an R&D project in North Sweden (financed by the steel industry and by the Swedish Energy Agency). By 2030, it is estimated that the share of VRE curtailment will be around 10-30%, which provides more incentives for hydrogen. While natural gas will be used for combined-cycle gas turbine for flexibility and while households are ‘*captive*’ for thermal uses, this will be progressively replaced with other ‘*renewable gases*’ (biomethane, other biogases, hydrogen and power-to-gas). However, by 2050, there will be even more pressure from the gas sector to include power-to-hydrogen and power-to-gas into national decarbonization scenarios, as they understood that natural gas will no longer be used. The stranded-assets in gas pipelines could provide some opportunities, for example by using a small quantity of hydrogen mix in the gas pipelines (or biomethane in the future), which is an observed European trend. Moreover, it can be envisaged that gas pipelines could transport in the future 100% renewable (or at least decarbonized) gas. Overall, when discussing the cost of hydrogen compared to curtailment, curtailment could be an alternative if reflected in the tariffs for end consumers.
- **Overarching challenges:** there was a clear understanding that we are moving beyond innovation in terms of generation technologies and increasing the installed renewable capacity, towards the electrification of end-use sectors with renewables. Overall, there seems to be two sets of challenges, depending on the resources available in the power system:
 - ⇒ On the one hand, there is a challenge in increasing the share of installed variable renewable capacity to reach a 100% renewable powered system, which calls for more flexible power systems, for which there is a wide variety of available technology-driven innovations (beyond generation technology innovations), as well as electricity market improvements.

⇒ On the other hand, there are examples of (near) 100% renewable power systems (e.g. Uruguay and Costa Rica), showing that it is feasible to reach this goal, by operating variable renewable energy sources with a large hydro-base. However, curtailment and making use of the surplus electricity is another key challenge that some countries are already facing, and others can expect to face it in the future. To overcome this challenge, electrification and sector coupling strategies can play an important role (e.g. heating in buildings, steel industry, transport and agriculture).

III. Next steps

As part of the experience-sharing programme on innovative solutions for very high shares of renewable power by mid-century, the next in-person workshop on “**Innovative solutions for 100% renewable power systems by mid-century**” will take place on **17 July 2019** in Montevideo, Uruguay, as part of the **IRENA Innovation Day**.

Registration is open via: innovationday@irena.org.

More information available at: <https://www.irena.org/events/2019/Jul/IRENA-Innovation-Day-Solutions-for-a-renewable-powered-future>

Past and upcoming events in 2019:

Type of workshop	Tentative date	Description	Location
Online	6 th June 2019	Focus on sharing national objectives for renewable power and expected/experienced challenges	Remote
In-person	17th July 2019	Focus on innovative solutions for 100% renewable power systems by mid-century by exchanging perspectives, plans and good practice in working towards very high levels of renewable power. Workshop takes place back-to-back with the IRENA Innovation Day (15-16 th July).	Montevideo, Uruguay
Online	October 2019 (TBC)	Focus on sharing national experiences with the application of innovative solutions	Remote

In-person	November 2019 (TBC)	Focus on disruptive innovative solutions enabling 100% renewable power systems	Europe (TBC)
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IV. Selection of IRENA's latest work on innovations

- **Innovation landscape for a renewable-powered future:**
<https://www.irena.org/publications/2019/Feb/Innovation-landscape-for-a-renewable-powered-future>
- **Innovation Outlook: Smart Charging for Electric Vehicles:**
https://irena.org/-/media/Files/IRENA/Agency/Publication/2019/May/IRENA_Innovation_Outlook_EV_smart_charging_2019.pdf
- **Hydrogen from renewable power: Technology outlook for the energy transition:**
<https://www.irena.org/publications/2018/Sep/Hydrogen-from-renewable-power>
- **Electrification with Renewables:**
<https://www.irena.org/publications/2019/Jan/Electrification-with-Renewables>