WORLD ENERGY COUNCIL

World Energy Perspectives | 2016

EXECUTIVE SUMMARY

VARIABLE RENEWABLES INTEGRATION IN ELECTRICITY SYSTEMS: HOW TO GET IT RIGHT

In the light of the growing importance of renewables and especially Variable Renewable Energy Sources (VRES) all over the world, policymakers and the industry need to address emerging issues to ensure continued growth of variable renewables and their successful integration in electricity systems. Drawing on case studies from 32 countries across five continents, the report *Variable Renewables Integration in Electricity Systems: How to get it right* highlights lessons learnt, identifies critical success factors and extracts practical solutions for success.

KEY FINDINGS

1 RENEWABLES, INCLUDING HYDROPOWER, NOW ACCOUNT FOR ABOUT 30% OF THE TOTAL GLOBAL INSTALLED POWER GENERATING CAPACITY AND 23% OF TOTAL GLOBAL ELECTRICITY PRODUCTION. In the last 10 years, wind and solar PV have witnessed an explosive average annual growth in installed capacity of 23% and 51% respectively, although their combined contribution to the global electricity production is around 4%.

2 RENEWABLES HAVE BECOME BIG BUSINESS: IN 2015 A RECORD USD286 BILLION WAS INVESTED IN 154GW OF NEW RENEWABLES CAPACITY (76% IN WIND AND PV), by far overtaking the investment in conventional generation to which 97 GW were added. There was a general market shift from developed countries to emerging economies. China alone accounted for 36% of global RES investments.

3 THE COMBINATION OF IMPROVING TECHNOLOGIES AND COST REDUCTIONS IS DRIVING DOWN CAPITAL EXPENDITURE (CAPEX) AND OPERATIONAL AND MAINTENANCE (O&M) COSTS of variable renewables, solar PV in particular. The most recent data available suggests the lowest auction value for wind is a tariff of USD28/MWh in Morocco and USD30/MWh for a 800 MW solar PV plant in Dubai. These exceptionally low values cannot generally be projected to other countries with different wind and sun load factors (in continental Europe, for example, they are up to 50% lower) and high local costs.

4 **BY 2015, 164 COUNTRIES AROUND THE WORLD HAD RENEWABLE ENERGY SUPPORT POLICIES IN PLACE;** 95 of them were developing countries, compared with 15 in 2005.

5 **THE EXAMPLE OF THE EUROPEAN UNION (EU) HIGHLIGHTS THE CONSEQUENCES OF REDUCTIONS IN SUBSIDIES** and other support schemes for investment in renewables: as subsidies decreased, the EU's share of global solar PV installed capacity dropped over the past four years from 75% to 41%, the share of wind from 41% to 33%.

RENEWABLES IN THE GLOBAL ENERGY SYSTEM:

World global power capacity additions and energy production by source 2004–2014

Source	Installed Capacity 2004 [GW] and (%) share		Installed Capacity 2014 [GW] and (%) share		Average Annual Growth Rate (%)	2014 Production [TWh] and (%) share		Average Equivalent Operating Hours [h]
Hydro	715GW	18.8%	1,055 GW	17.1%	4%	3,898TWh	16.6%	3,694
Wind	48GW	1.3%	370GW	6.0%	23%	728TWh	3.1%	1,967
Biomass	39GW	1.0%	93GW	1.5%	9%	423TWh	1.8%	4,545
Solar	3GW	0.1%	181GW	2.9%	51%	211TWh	0.9%	1,168
Geothermal	9GW	0.2%	13GW	0.2%	4%	94TWh	0.4%	7,225
Total Renewables	814GW	21.4%	1,712GW	27.7%	8%	5,353TWh	22.8%	3,127
Total Conventional (Oil, Gas, Coal) and Nuclear	2,986GW	78.6%	4,468GW	72.3%	4%	18,127TWh	77.2%	4,057
TOTAL	**3,800GW**	**100%**	**6,180GW**	**100%**	**5%**	**23,480TWh**	**100%**	**3,799**

Source: CESI S.p.A., based on REN21 2015

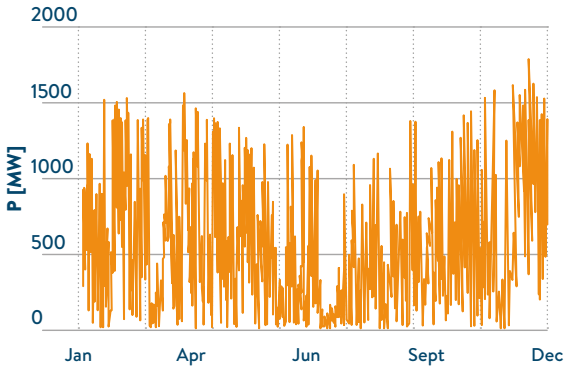
6 **A RIGHT LOCATION WITH HIGH WIND OR SOLAR LOAD FACTORS AND LOW GRID CONNECTION COSTS** is the key to success for new, large variable renewables projects.

7 **A REAL CHALLENGE FOR VARIABLE RENEWABLES INTEGRATION IS TO RAPIDLY MANAGE THE IMPLICATIONS OF VARIABLE NATURE OF WIND AND SUN.**

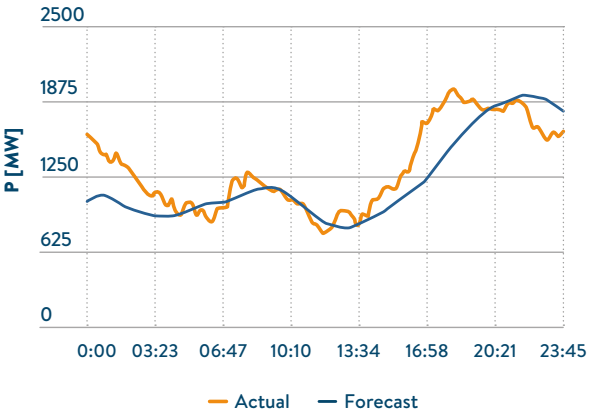
The graphs below illustrate the effects of wind variability in Ireland on the global wind fleet power production and of variations of sun on a small PV installation in central Italy.

YEARLY AND DAILY VARIABILITY IN IRELAND OF GLOBAL WIND FLEET POWER PRODUCTION

YEARLY

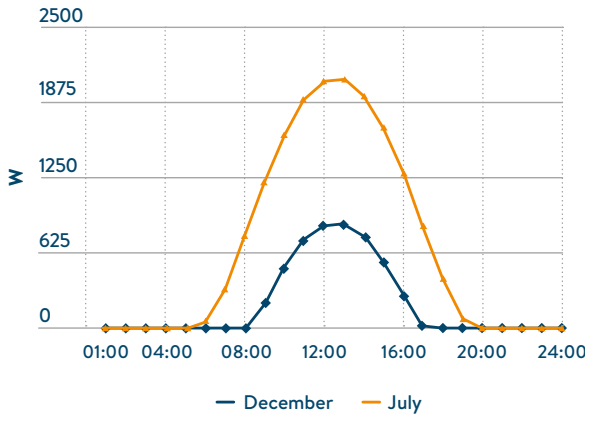


DAILY



SEASONAL AND DAILY EFFECTS OF SUN VARIATION ON THE POWER GENERATION OF A SMALL PV PLANT IN CENTRAL ITALY

SEASONALITY



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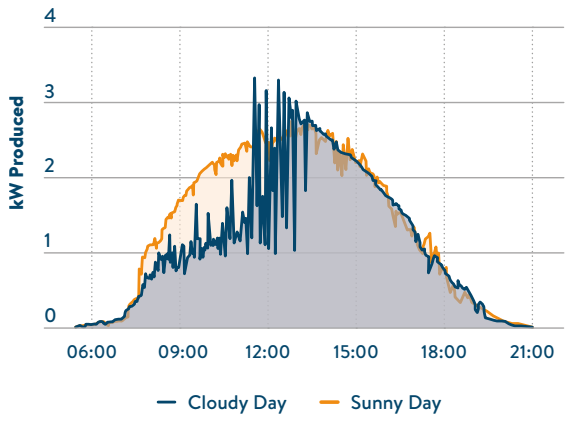

Source: CESI S.p.A

RECOMMENDATIONS

The increasing use of variable renewables still presents a number of challenges. Effective and affordable technology solutions will help decrease or eliminate these challenges. Appropriate policies, including regulation and market design play a fundamental role in both development of variable renewables and their efficient integration in electricity systems.

Solutions for the main challenges can be divided into two complementary categories **Policies** and **Technologies**.

Policies and Market Design

- **A holistic and long-term approach** to system design is key when planning variable renewables integration. Each country's power system is unique depending on its primary energy sources, location and size of power plants, transmission and distribution (T&D) systems, financial conditions, costs and consumer behaviour.

- **Market redesign**: Policymakers must design market rules to ensure a more sustainable energy system in line with the objectives of the Trilemma, including clearly defined CO_2 emissions regulations.

- **Introduction of capacity markets** can help ensure security of supply, as energy-only based markets are often insufficient to guarantee supply in systems with a large share of variable renewables.

- **Adjustments to existing market design** can be efficient, for example:

    - **Larger balancing areas:** Sharing the implications of variability and load forecast errors across a broader region provides a natural reduction in the system balancing costs.
    - **Aggregating the bids** of different plants in the market can facilitate a reduction in the overall variability of electricity supply and thus reduce the forecast errors and system balancing needs.
    - **Ancillary services** can be provided by variable renewables, even in the absence of sun and wind, with help of new inverter technologies. Responsibilities for system balancing have to be shared fairly among market participants, including variable renewables generators.
    - **Hourly and sub-hourly scheduling:** Taking into account the technical limitations of conventional plants for more efficient use of available transmission and generation capacity.
    - **Nodal pricing** demonstrates the benefits of an appropriate selection of location for renewables power plant and as a result, a smoother integration of intermittent renewable generation technologies.

- **Looking at the costs**: Policymakers and the industry are encouraged to conduct thorough technical and economic analyses with comprehensive assessment which, in addition to VRES CAPEX and O&M, include the associated costs for the complete power system.

Technologies

- **Improving weather forecasts:** Weather forecasting methodologies need further development to achieve better accuracy.

- **Advanced operating procedures to optimise reserve capacity and flexibility of conventional generation** should be introduced to manage intermittency and variability.

- **Demand response,** i.e. the short-term adjustment of demand to address temporary shortage or excess power from variable renewables, must be developed further.

- **Energy storage technologies** can be a game-changer and contribute to addressing the intermittency challenge.
  See the Council's 2016 report on E-storage **www.worldenergy.org/publications/2016/e-storage-shifting-from-cost-to-value-2016**

- **An expansion of the transmission and distribution grids,** including cross-border interconnections, may be necessary together with an optimum operational cooperation between TSO's and DSO's.

ABOUT THIS REPORT

The report ***Variable Renewable Energy Sources Electricity Systems Integration: How to get it right*** highlights the issues associated with the increasing share of variable renewable energy sources for electric power systems' operation. It examines integration of wind and solar PV in electricity systems and formulates recommendations for policymakers and the industry. The 32 country case studies provide a snapshot of the experiences and the different approaches that were implemented in different countries. The report provides a reality check and will help facilitate the development of technically and economically sound policies and regulations. The report has been produced in collaboration with **Project Supporter and the Council's Global Partner, CESI S.p.A., Italy**, with contributions from the 48 members of the Knowledge Network on Renewable Energy Sources Electricity Systems Integration.

ABOUT THE WORLD ENERGY COUNCIL

The World Energy Council is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all. It is the UN-accredited global energy body, representing the entire energy spectrum, with member organisations in over 90 countries.

Further details at **www.worldenergy.org** and **@WECouncil**

The full report and detailed country case studies can be found at **www.worldenergy.org/publications**

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