New Energy and Weather Services in the Context of the Energy Transition

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The potential of weather forecasting is increasingly being exploited by power generators and transmission-system operators as renewable electricity generation has become a significant and increasing part of the energy mix in many countries. Showing how the forecasts are interpreted and actually used, we suggest avenues for policy makers on how best utilizing meteorology in the unfolding energy transition through new, integrated meteorology and energy services.

1. Introduction

A global solar photovoltaic[1] (PV) and wind[2] renewable electricity boom is gaining momentum across the world, with worldwide PV and wind capacity having reached, respectively, 310 and 500 GW nominal power by the end of 2016. This adds to the large hydro-power capacity installed worldwide (1064 GW by the end of 2016) generating 16.4% of the world's electricity.[3] Only in the first seven months of 2017, China installed and connected to the grid 35 GW of additional PV power.[4] In brief, renewable energy has rapidly emerged as a significant alternative to fossil fuel-derived energy, with traditional energy market being impacted in all countries where a significant share of the energy mix is produced from renewable energy sources. For example, in Germany, the price of electricity on the wholesale market has gone from €60 per MWh in early 2011 to €28.96 per MWh in 2016, when the world's fourth largest economy hosted the world's second largest national PV (40 GW) and third largest wind (50 GW) parks, with wind and solar electricity fed into the grid at very low and even zero price on a priority basis, forcing off the market natural-gas- and coal-fired power plants.[5]

Weather variability has a direct and significant impact on the availability of energy in its most useful and dispatchable form (electricity), as the amount of sunshine/radiation, rainfall, and wind speed today directly impacts PV and hydro- and wind power generation (the supply), whereas other climatic variables such as temperature and humidity mostly affect its demand. This has created the field of energy meteorology,[6] with the inaugural international conference held in 2011,[7] and the first comprehensive book providing an overview on renewable energy forecasting methodologies and applications published in 2017.[8]

Because renewable energy sources are highly weather sensitive (hydropower requiring rainfall, PV sunshine, and wind power ventilation), meteorology and climate science have become essential tools for improving the utilization of renewable energy through integration of large amounts of solar, wind, and hydropower into the grid as well as for local renewable-energy users self-generating energy in the new distributed-generation system.[9]

The approach to predicting solar and wind power generation from up to several hours to a few days is becoming commonplace in many countries. Examples go from small countries such as Oman, using weather forecast to maximize solar electricity input into the grid,[10] to large nations such as the United States of America, where a high-resolution, rapid weather prediction system was recently made available.[11] The debate is open whether a 100% renewable-energy scenario in 2050, such as that proposed for the United States of America,[12] Germany,[13] Italy[14] and for many other highly industrialized nations, is realistically feasible.[15] In the following, we show how weather information is actually used to facilitate the production and use of renewable energy, suggesting avenues for regional policy makers on how to utilize meteorology as an essential tool in the transition to full renewable energy through new, integrated meteorology and energy services.

2. Weather and Energy: From Demand to Supply Management

The reason why renewable energy producers obtain significant economic benefits from the ability to forecast weather and estimate the actual energy production is neatly rendered

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by Figure 1. The plots therein show how the energy produced by a PV plant in Sardinia without forecasting in 2007 was sold at flat, low price on the zonal electricity market, whereas in 2010 it was sold at significantly higher prices placing offers on the day-ahead market following demand, which can be attributed to accurate prediction of the plant production based on the neural-network approach to forecasting.[16]

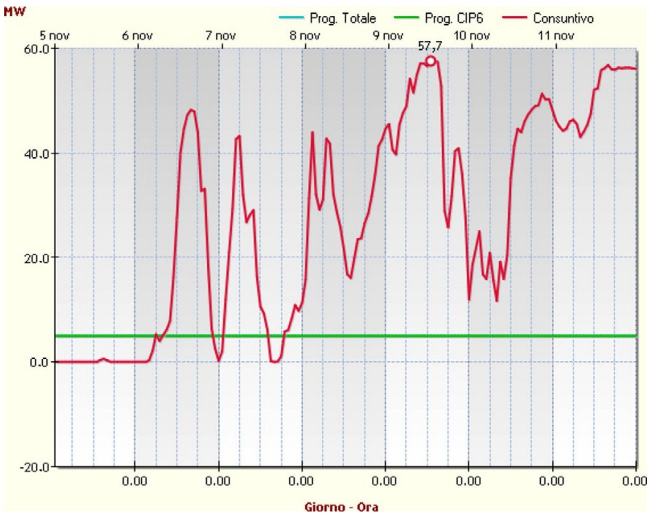


Figure 1. Power production of a PV plant in Sardinia in 2007 (top) and in 2010 (bottom); and market price of the electricity generated without and with forecasting of energy production (green line). Reproduced from Ref. [16], with kind permission.

This explains also why, among the three main needs of meteorological information for the energy industry lately identified (to improve knowledge of meteorological data and processes; to provide trusted information to the energy industry; and to improve access to meteorological and energy data),[17] the need to provide the energy industry with accurate meteorological and energy forecasting services has been, most likely, the main driving force that led to the foundation of the energy and weather research field. Indeed, the stated aim of the World Energy & Meteorology Council (established in 2015 at the University of East Anglia in the United Kingdom) is "to promote and enhance the interaction between the energy and the weather forecast communities enabling the energy industry to adopt weather and climate information, so as to maximize clean energy production and dispatchment".[18]

Up to about 15 years ago, large thermoelectric and large hydropower electricity producers relied on weather forecasts to plan power generation based on straightforward meteorological effects upon consumption (the demand). Nowadays, conversely, managers of the electric grid and electricity producers rely on weather forecasts to predict the generation from the large and rapidly growing installed renewable capacity (the supply), which acts as a further constraint on conventional generation to maximize the amount of clean power offered and traded on the market.

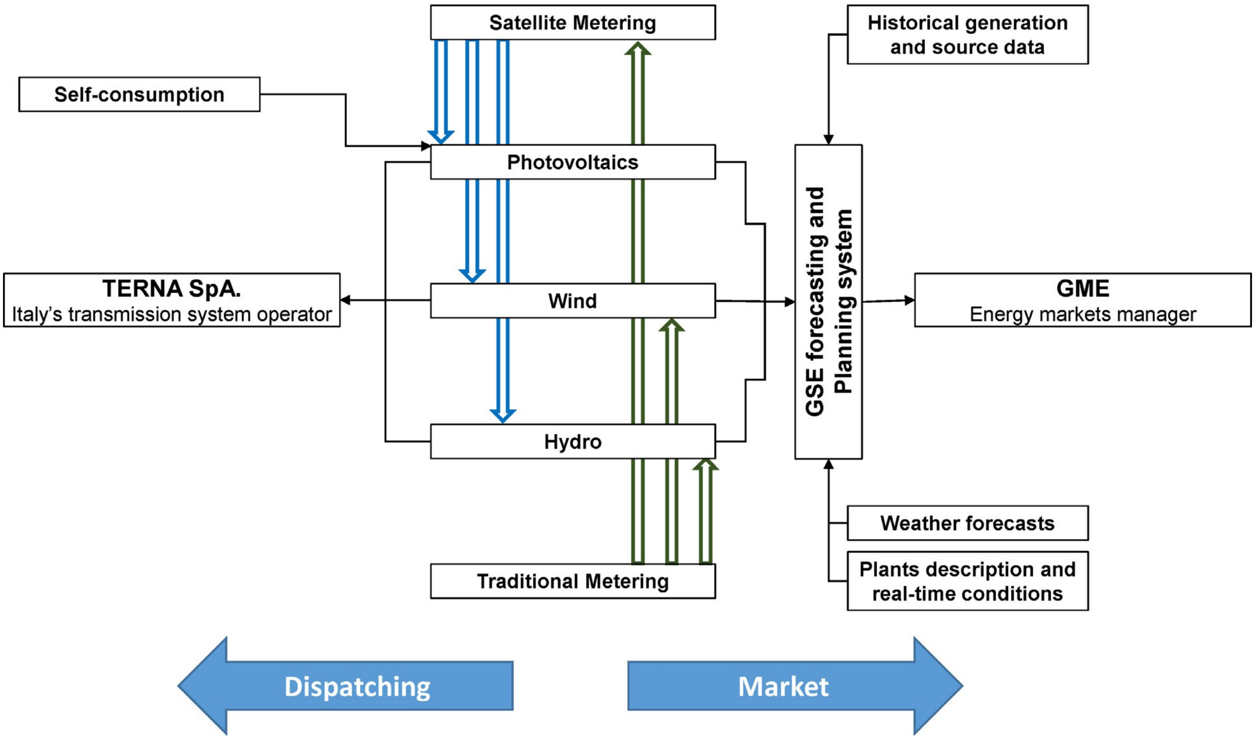
In other words, the dramatic growth of renewable energy occurred in the last 15 years, in Europe first and across the entire world later, has changed the scope of meteorology in the energy sector from a tool to improve the risk management of energy to a more comprehensive objective of improving the resilience of today's energy systems in which water, wind, and sun play a crucial role. Numerous meteorological tools are already available for such predictions, from the Anemos[19] or the Anfis[20] models used for wind-power forecasting in Europe or in China to the European climatic energy mixes (ECEM) model to integrate weather forecasts with climate models, to enable assessment of how well different energy supply mixes will meet the demand of electricity in Europe.[21]

What is essential to understand is that these tools provide datasets that allow the prediction of wind availability and solar radiation in different geographical and time domains, assisting the regional (and national) planning and optimization of renewable and overall electricity generation and dispatchment.

3. The Case of Italy

Exceeding 7.2% of the overall electricity demand (310 TWh), PV energy in Italy in 2016 had the largest share in the energy mix of highly industrialized countries.[22] The deployment of the feed-in-tariff (FiT) incentive scheme in Italy between 2006 and 2013, and the simultaneous and at least partially consequent fall in price of PV systems caused an impressive surge in the PV-installed power nationwide. Besides benefiting the environment,[23] Italy's large PV park (19.3 GW by the end of 2016) generates over 22 TWh of electricity concentrated in the central hours of the day of sunny months perfectly correlating with customer demand; this has significantly reduced the price of electricity in the Italian wholesale electricity market (IPEX).[24] Furthermore, the decentralized nature of PV energy fed into the distribution grid in proximity to its users reduces operating costs related to the transmission grid while offering local voltage regulation, namely a valued grid service that improves grid stability and quality.[25]

To ease the management of the rapidly increasing renewable energy flows, Italy's transmission system operator (Terna) requires from Italy's energy services operator (GSE), which withdraws and sells on the market all the electricity from renewable energy source (RES) plants earning public incentives, an estimate of RES-sourced electricity fed to the grid on the day ahead. In 2015, for example, GSE withdrew from the owners of renewable-energy plants and sold on the IPEX market about 40 TWh out of 315 TWh consumed in the country in that year.[26] The national regulatory authority, which is responsible for defining the rules for attributing costs related to imbalances to all power plants (RES and non-RES), lately revised the procedures for allocating the costs of imbalances to be paid by RES power plants. In brief, in case a RES plant feeds a lower (negative unbalance) or higher (positive unbalance) amount of electricity, fees pro-



Scheme 1. Model used by Italy's Energy Services Operator to forecast energy production on the day-ahead market and inform bids on the IPEX market managed by GME. Reproduced from Ref. [28], with kind permission.

portional to the amount of the imbalances are charged.[27] To reduce energy imbalances, and related costs, the GSE performs accurate forecasting of the energy generated by non-programmable wind and PV power sources since 2012 using meteorological modeling to predict energy production in the subsequent three days (Scheme 1).[28]

In detail, the operator performs weather and energy production forecasting for a large number of power plants all over the country. The weather forecast models are run twice per day (at 7:00 and 18:00) for each significant plant in a specific market zone. The output are hourly curves for the subsequent 3 days for each plant in each market zone, through which the energy operator optimizes its electricity bid on the IPEX market for the day ahead. Progress has been dramatic. A state-of-the-art energy-monitoring infrastructure using satellite communication allows the operator to monitor almost in real time the energy generation from about 3000 renewable energy plants, including hydroelectric ones.

In 2010, almost 26 % of the electricity retrieved by the operator was unbalanced (Table 1). In 2015, the share was reduced to a mere 0.2 %, with a negative unbalance amounting merely to 45.125 GWh out of almost 30 TWh retrieved from RES-sourced plants. It is also interesting to note that, in 2011, renewable energy companies producing photovoltaic and wind electricity in Sicily spent €108 million on the real-time balancing market,[29] with €24.17 million paid to balance PV plants and €83.84 million to balance wind plants because forecasting of non-periodical wind velocity is a bigger challenge than forecasting solar radiation, which adds to the fact

Table 1. Volumes and overall incidence of electricity imbalances from Italy's RES-sourced non programmable plants managed by GSE, 2010–2015. Reproduced from Ref. [26], with kind permission.

Year	Electricity withdrawn [GWh]	Imbalances [GWh]	Incidence [%]
2010	11 934.351	3091.313	25.9
2011	21 048.836	9001.716	42.8
2012	30 985.950	2678.817	8.6
2013	33 268.499	876.106	2.6
2014	33 681.370	−413.176	1.2
2015	28 956.699	−45.125	0.2

that wind velocity relates to wind energy to the third power, magnifying any forecasting error.

4. Policy Recommendations

As the energy transition to 100 % renewable energy unfolds in countries and regions of the world, the creation of new regional energy and weather services at regional level is highly recommended. These could be based within regional government departments or within local research institutes. When existing, such new centers integrating the production of weather and energy information would optimally rely on regional and national best practices. For example, willing to create one such center in Sicily, namely Italy's largest region where significant PV (1.4 GW) and wind (1.9 GW) power were installed in a few years has changed the zonal electricity price formation to such an extent that it caused a significant decrease in the national electricity price,[30] the new service would integrate its activities with the Sicilian Agrometeorological Information Service, for which about 100 meteorological stations were installed across the whole island in the early 2000s.[31]

Furthermore, the new center could rely on support from the LaMMA—the Laboratory of Meteorology and Environmental Modeling incorporated from the Environmental Modelling and Monitoring Laboratory for Sustainable Development consortium in late 2007, which was established in 1997 by the Region of Tuscany along with Italy's Research Council Institute of Biometeorology. Along with a reputed meteorology service running an advanced and continuously updated operational chain for 20 years already,[32]LaMMA's researchers developed a model to map regional wind energy resources at very high spatial (2 km) resolution, integrating meteorological and technological information.[33] Hourly wind estimates were calculated after coupling the Weather Research and Forecasting prognostic mesoscale model (10 km horizontal resolution, hourly forecasts from 0 to 24 h lead time) with the CALMET (California meteorological model) diagnostic wind model (2 km horizontal resolution), over the Tuscany region during a 4 year period (2004–2007). Based on the hourly wind speed estimates at each grid point, at a reference hub height of 75 m above the local terrain, the Weibull probability density function was applied to derive the wind speed frequency distribution, which in turn allows computing the Betz annual specific energy, availability, and capacity factors; annual energy production; full-load hours; and eventually the annual energy production versus turbine power curve for more than 200 wind generators available at that time.[34] In addition, all relevant exclusion layers were mapped, such as archaeological and landscape constraint, parks, reserves and natural areas, besides conventional geographical features. The resulting "WIND-GIS" (WIND-GIS = wind geographic information system) is available in a web-oriented interactive system, freely accessible by operators. In comparison with state-of-the-art systems available at that time (2011–2012), the "WIND-GIS" system was rather advanced and among the few offered on an interactive freely accessible GIS-based platform. The system was made available including all exclusion layers, at the highest spatial horizontal resolution in Europe, along with that of WRMS (a private weather forecasting agency) system covering Switzerland, which was built on statistical interpolation of sparse station measurements.[35]

Without the political will that led Germany first, followed by Spain, Italy, and Greece in Europe and subsequently by China to establish the FiT incentives mitigating the financial risk for investors, today's ultralow prices of solar PV modules would never have been reached. The fall in price has gone beyond any expectation, and now solar electricity generated using PV modules has become cheaper than coal-based electricity with huge countries such as India undergoing massive solarization using auctions for huge solar parks based on 20-year power purchase agreements, with 1 kWh profitably achieving US$0.038.[36] Now that dramatic cost reduction has made solar energy accessible to all, political will should be broadened to encompass other factors to guide and drive the energy transition. As Hermann Scheer compellingly writes:[37]

> To be able to discuss energy as a separate matter is an intellectual illusion. The CO_2 emissions are not the only problem of fossil energy. The radioactive contamination is not the only problem of atomic power. Many other dangers are caused by using atomic and fossil energies: from the polluted cities to the erosion of rural areas; from water pollution to desertification; from mass migration to overcrowded settlements and the declining security of individuals and states. Because the present energy system lies at the root of these problems, renewables are the solution to these problems.

Recognizing that the transition from fossil-fuel and nuclear energy to renewable energy is an economic, environmental, health, and ultimately moral imperative,[33] new-generation decision makers will proactively act and include the foundation of new renewable energy research and educational centers providing the weather and energy services discussed in this study as a cornerstone of new energy policies, along with the required shifts in regulations, pricing regimes, and the behavior of users identified by Sovacool in a recent conceptualization study on energy transitions.[38]

5. Outlook and Conclusions

Using the case of Italy, this study shows why and how new energy and weather services should be established at regional level to meet the new weather and climate knowledge requirements of solar economy practitioners, which include transmission system operators, utilities, renewable-energy-plant and biorefinery owners, local communities, and single owners of solar energy systems. Current policies in other countries such as Germany, Spain, and Canada, to mention a few selected countries, indicate a similar trend. In Germany, the Ministry for economic affairs and energy financed a four year research project in 2012 that includes the major grid operators, which was funded with the aim to provide grid operators with predicted renewable power generation over the next 48 h to maximize renewable power input to the grid and minimize that from conventional themoelectric plants.[39] In Spain, where wind power covers 19% of the country's demand, the Control Center of Renewable Energies uses a neural network-based forecast model (Sipreolico), for which the accuracy was improved considerably between 2008 and 2013; since then, the performance remained practically unvaried mostly because of limitations of the weather prediction models.[40] A recent study on how to optimally use probabilistic forecasts for renewable energy generation[41] mentions as good practice a training course aimed at both forecast users and providers created by the Meteorological Service of Canada. Finally, in China, where by far the world's largest national PV and wind power parks are installed, the State Grid Corporation of China extensively uses real-time weather forecasting systems developed by its Chinese Electric Power Research Institute to meet the needs for power generation to enhance and maximize the amount of electricity that can be integrated into the grid from PV plants and wind farms to ensure electric transport safety.[42]

Similar to a previous study in which we identify the need for regional solar-energy and bioeconomy institutes,[43] the arguments of the present study, in brief, extend well beyond Italy, as societies in both developed and developing countries look to distributed generation of renewable energy from water, sun, and wind as a viable means to get rid of pollution and dependence on fossil fuels and also to biomass replacing petroleum as a sustainable raw material for the production of chemicals, polymers, and functional materials.[44]

In the context of the energy transition, accurate weather forecasting becomes as important as intelligent grid management and increased storage capacity. As the energy system undergoes profound transformations due to rapid emergence of the solar economy, following Wentland and co-workers[45] we find that previously separate scientific and technology domains start to interact, serving new societal sustainability needs. For example, professionals working in such new energy and weather services will need to develop significant competence in public outreach and communication of weather and energy forecasts.[46] Hence, the education of professionals capable of proactively acting based on such cross-disciplinary knowledge[47]will be a central task of these new energy and weather centers.

Fifteen years after Scheer's book[48] on the solar economy, compelling evidence suggests that "helionomics" is not an utopia nor an unrealistic and far-fetched scenario. The arguments of this study will hopefully contribute to its further progress.

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Conflict of interest

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[1] F. Meneguzzo, R. Ciriminna, L. Albanese, M. Pagliaro, *Energy Sci. Eng.* **2015**, *3*, 499.
[2] World Wind Energy Association, WWEA Half-Year Report: World Wind Capacity Reached 456 GW, Bonn: October 10, **2016**, http://www.wwindea.org/wwea-half-year-report-worldwind-wind-capacity-reached-456-gw/.
[3] World Energy Council, 2017. See at the URL: www.worldenergy.org/data/resources/resource/hydropower/.
[4] M. Osborne, China installs 10.52 GW of solar in July: Exceeds 2020 target by 7%, https://www.pv-tech.org/news/china-installs-10.52gw-of-solar-in-july-exceeds-2020-target-by-7, 22 August 2017.
[5] J. Flauger, F. Hubik, *Electricity Prices in Free Fall* in *Handelsblatt*, 23 March 2016.
[6] S. Lee, R. Burton, G. Masato, D. Brayshaw, Deriving local wind speeds for a wind farm and a biocrop site using Grosswetterlagen weather types and the Weather Research and Forecasting model, *Renewable energy and future of energy meteorology*, Royal Meteorological Society, London, 17 October 2012.
[7] *International Conference Energy & Meteorology 2011*, Gold Coast, Queensland, Australia, 8–11 November 2011.
[8] G. Kariniotakis, *Renewable Energy Forecasting: From Models to Applications*, Woodhead Publishing, London, **2017**.
[9] A. Colmenar-Santos, C. Reino-Rio, D. Borge-Diez, E. Collado-Fernandz, *Renewable Sustainable Energy Rev.* **2016**, *59*, 1130–1148.
[10] Y. Charabi, A. Gastli, S. Al-Yahyai, *Energy Rep.* **2016**, *2*, 67–73.
[11] E. P. James, S. G. Benjamin, M. Marquis, *Renewable Energy* **2017**, *102*, 390–405.
[12] M. Z. Jacobson, M. A. Delucchi, G. Bazouin, Z. A. F. Bauer, C. C. Heavey, E. Fisher, S. B. Morris, D. J. Y. Piekutowski, T. A. Vencill, T. W. Yeskoo, *Energy Environ. Sci.* **2015**, *8*, 2093–2117.
[13] A. Palzer, H.-M. Henning, *Energy Technol.* **2014**, *2*, 13–28.
[14] F. Meneguzzo, R. Ciriminna, L. Albanese, M. Pagliaro, arXiv:1609.08380 [physics.soc-ph].
[15] V. Smil, *Energy Transitions: Global and National Perspectives*, Praeger, Santa Barbara (CA), **2017**.
[16] G. Niglio, La previsione delle immissioni di energia elettrica da fonti rinnovabili quale meccanismo di integrazione delle reti di distribuzione, l'esperienza del GSE, *AEIT Giornata di Studio Smart Grids*, Catania 9 November 2010, http://www.cepsrl.it/wp-content/uploads/2010/11/3a.-giornata-di-studio-aeit-gse-niglio.pdf.
[17] A. Troccoli, Energy & Meteorology Nexus, *6th IEA Forum on Climate-Energy Security Nexus*, 7 June 2016, Ottawa, Canada.
[18] See at the URL: www.wemcouncil.org/wp/.
[19] G. Kariniotakis, I. H. P. Waldl, I. Marti, G. Giebel, T. S. Nielsen, J. Tambke, J. Usaola, F. Dierich, A. Bocquet, S. Virlot, Next generation forecasting tools for the optimal management of wind generation, *2006 International Conference on Probabilistic Methods Applied to Power Systems*, Stockholm, **2006**, https://doi.org/10.1109/PMAPS.2006.360238.
[20] Y. Kassa, J. H. Zhang, D. H. Zheng, D. Wei, Short Term Wind Power Prediction Using ANFIS, *2016 IEEE International Conference on Power and Renewable Energy (ICPRE)*, Shanghai, **2016**, pp. 388–393, https://doi.org/10.1109/ICPRE.2016.7871238.
[21] See at the URL: https://climate.copernicus.eu/ecem.
[22] Terna SpA, Rapporto Mensile sul Sistema Elettrico Consuntivo Dicembre 2016, Rome, **2016**, download.terna.it/terna/0000/0784/89.PDF.
[23] A. Louwen, W. G. J. H. M. van Sark, A. P. C. Faaij, R. E. Schropp, *Nat. Commun.* **2016**, *7*, 13728.
[24] M. Pagliaro, F. Meneguzzo, F. Zabini, R. Ciriminna, *Energy Sci. Eng.* **2014**, *2*, 94–105.
[25] Rolle der Solarstromerzeugung in zukünftigen Energieversorgungsstrukturen—Welche Wertigkeit hat Solarstrom?, investigation commissioned by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety, May 2008, https://www.tib.eu/de/suchen/id/TIBKAT%3A590633074/Studie-Rolle-der-Solarstromerzeugung-in-zuk%C3%BCnftigen/.
[26] GSE, *Rapporto Attività 2015*, Rome, **2016**, http://www.gse.it/ layouts/GSE Portal2011.Structures/GSEPortal2011 FileDownload.aspx?FileUrl=http://www.gse.it//it/Dati%20e%20Bilanci//GSE Documenti%2fRapporto+Attivit%c3%a0%2fRapporto+2015+delle+attivit%c3%a0+del+Gestore+dei+Servizi+Energetici.pdf&SiteUrl=http://www.gse.it//it/Dati%20e%20Bilanci/.
[27] The hourly imbalance prices according to zones and type of unit are calculated in compliance with AEEG Resolution No. 111/06.
[28] L. Benedetti, Lesson learned in the deployment of RE distributed systems in Italy, *RES4MED Days—A step change in the deployment of RE and EE solutions in the Mediterranean*, Rabat, 16 September 2014.

[29] N. Ibagón C., Analysis of European RES Imbalance Charges: The Impact on PV and Wind Plants, Politecnico di Milano, Milan: 2014. Available at the URL: https://www.politesi.polimi.it/bitstream/10589/86586/3/2013_12_Ibagon.pdf.
[30] F. Meneguzzo, R. Ciriminna, L. Albanese, M. Pagliaro, *Energy Sci. Eng.* **2016**, *4*, 194–204.
[31] www.sias.regione.sicilia.it.
[32] "Implementing an Operational Chain: The Florence LaMMA Laboratory": A. Ortolani, A. Antonini, G. Giuliani, S. Melani, F. Meneguzzo, G. Messeri, G. M. Pasqui in *Measuring Precipitation From Space* (Eds.: V. Levizzani, P. Bauer, F. J. Turk), Springer, Berlin, **2007**, pp. 471–482.
[33] R. Mari, L. Bottai, C. Busillo, F. Calastrini, B. Gozzini, B. G. Gualtieri, *Renewable Energy* **2011**, *36*, 754–763.
[34] G. Gualtieri, *Int. J. Renewable Energy Res.* **2012**, *2*, 674–685.
[35] Suisse Eole, *The Swiss wind power data website*, 2010. Available at the URL: http://www.wind-data.ch/windkarte (last time accessed, September 21, 2017).
[36] T. Kenning, Yet another India solar tariff record of 2.44 rupees in Rajasthan, https://www.pv-tech.org/news/yet-another-india-solar-tariff-record-of-2.44-rupees-in-rajasthan, 12 May 2017.
[37] H. Scheer, *A Solar Manifesto, 2nd ed.*, Earthscan/James & James, London, **2005**.
[38] B. H. Sovacool, *Energy Res. Soc. Sci.* **2016**, *13*, 202–215.
[39] Q. Schiermeier, *Nature* **2016**, *535*, 212–213.
[40] A. Rodriguez, Wind generation forecasting at REE, *Experiences in Using Wind Power Predictions and Gaps in Forecasting Research Workshop*, IEA Wind Task 36, Barcelona, 9 June 2016.
[41] R. Bessa, C. Möhrlen, V. Fundel, M. Siefert, J. Browell, S. Haglund El Gaidi, B.-M. Hodge, Ü. Cali, G. Kariniotakis, *Energies* **2017**, *10*, 1402.
[42] Y. Liu, Real-time weather forecasting systems for supporting power grid O&M at the State Grid Corporation of China, *4th International Conference Energy & Meteorology*, Bari (Italy), 28 June 2017.
[43] M. Pagliaro, F. Meneguzzo, *Chem. Eur. J.* https://doi.org/10.1002/chem.201703146.
[44] M. Pagliaro, *Preprints* **2017**, 2017070062. https://doi.org/10.20944/preprints201707.0062.v1.
[45] W. Canzler, F. Engels, J.-C. Rogge, D. Simon, A. Wentland, *Energy Res. Soc. Sci.* **2017**, *27*, 25–35.
[46] F. Zabini, *Met. Apps.* **2016**, *23*, 663–670.
[47] R. Ciriminna, F. Meneguzzo, M. Pecoraino, M. Pagliaro, *Renewable Sustainable Energy Rev.* **2016**, *63*, 13–18.
[48] H. Scheer, *The Solar Economy*, Earthscan, London, **2002**.

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