HOW MUCH EXTREME WEATHER EVENTS HAVE AFFECTED EUROPEAN POWER GENERATION IN THE PAST 30 YEARS?

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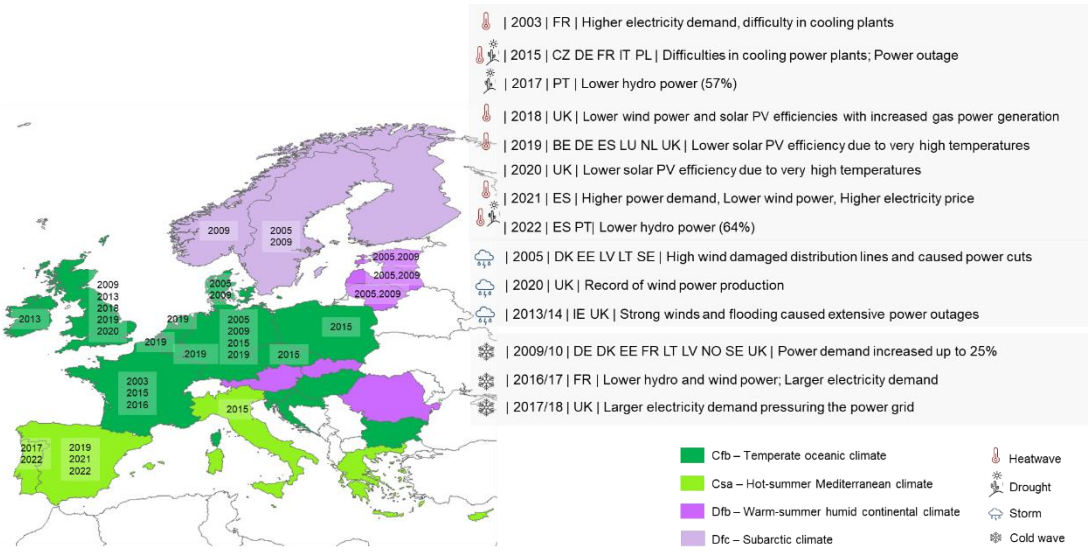
WHY IS KEY TO ASSESS THE EFFECTS OF EXTREME WEATHER EVENTS ON POWER GENERATION?

Power generation impacts due to **extreme weather events** (EWE), as floods, storms, cold waves, droughts, and heatwaves, are **not well understood** across larger spatial scales, especially in view of climate change. These **events can severely affect our energy supply** by interrupting the energy generation or its transmission, by interfering with fuel production and distribution, or by causing fuel and electricity shortages, potentially leading to price spikes.

EWE are **expected to increase in frequency and severity under climate change** [1], potentially **exacerbating the vulnerabilities of the power system** and affecting supply reliability [2]. Particularly, the **power capacity of renewables**, as wind, hydro, solar photovoltaic (PV) is **highly dependent on weather** conditions.

In 2019, across the European Union (EU), UK and Norway (EU+), **renewable energy** represented nearly 33% of total European electricity production, a number that increased by 12% since 2010 [3], and that is planned to increase more **in the EU** as a **key strategy to decarbonization and to reduce climate change** [4], [5].

Increasing the use of European renewable energy, as aligned with the EU energy targets, will require **careful planning** to ensure that **risks from EWE** are properly **managed**, and to **guarantee** the **resilience**, **reliability**, and **stability of the power system. At LNEG we quantified historic impact of EWE on annual power plants generation in EU+ from 1990 to 2019** [6]**.**



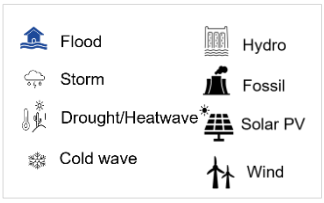
Exemplifying Extreme Weather Events and corresponding effects on power sector across Europe

WHAT ARE THE IMPACTS OF EWE ON POWER GENERATION AT THE EU+ LEVEL?

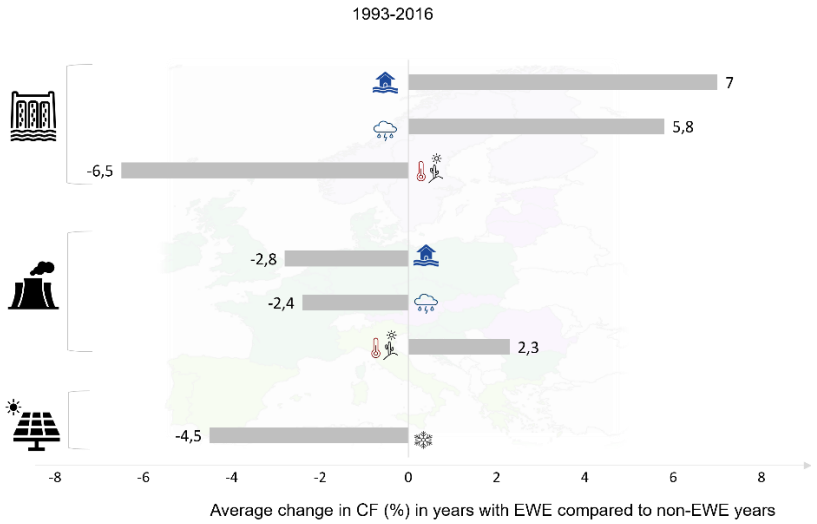
From **1990-2019**, EM-DAT (The International Disaster Database, [7]) lists 320 events causing human/economic damages in the EU+:

- 108 floods
- 106 storms
- 12 droughts
- 41 heatwaves
- 53 cold waves

Capacity Factor (CF) represents the actual power generation of a given power plant (or group of plants) as a fraction of total maximum possible generated power considering its installed capacity throughout a whole year

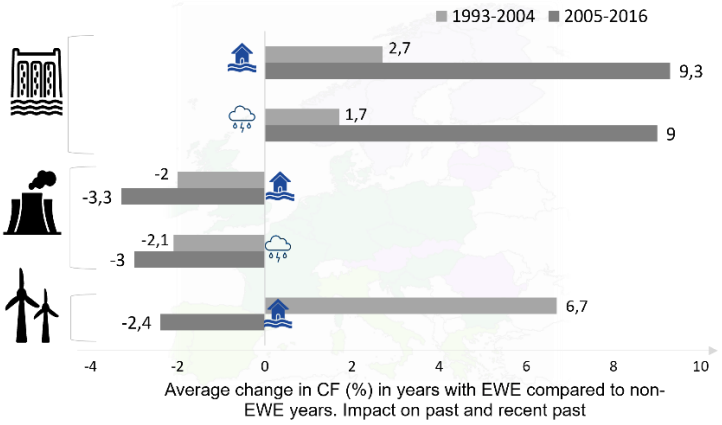


- **Hydro and fossil power plants** are significantly **affected by floods, storms, droughts and heatwaves**, at the European level
- **During the past 30yrs a flood year** increased, on average, the **annual EU+ hydropower capacity factor by +7% more** compared to non-flood years
- **In years with storms** the **annual EU+ hydropower increased by +5.8%,** while **droughts/heatwaves lowered it by -6.5%**
- **Fossil power plants are less used during flood** (-2.8%) **and storm years** (-2.4%), and more used **during droughts/heatwaves years** (+2.3%), possibly due to the need to compensate lower hydropower, generation. In EU+, in 2019, hydropower represented 16% of the total electricity generation [8]



**No statistically significant impacts were obtained, at the EU+ level, on wind power plants for the entire time period – only for two smaller time periods (see next section)*

AT THE EU+ LEVEL EWE IMPACTS ON POWER GENERATION ARE CHANGING OVER TIME



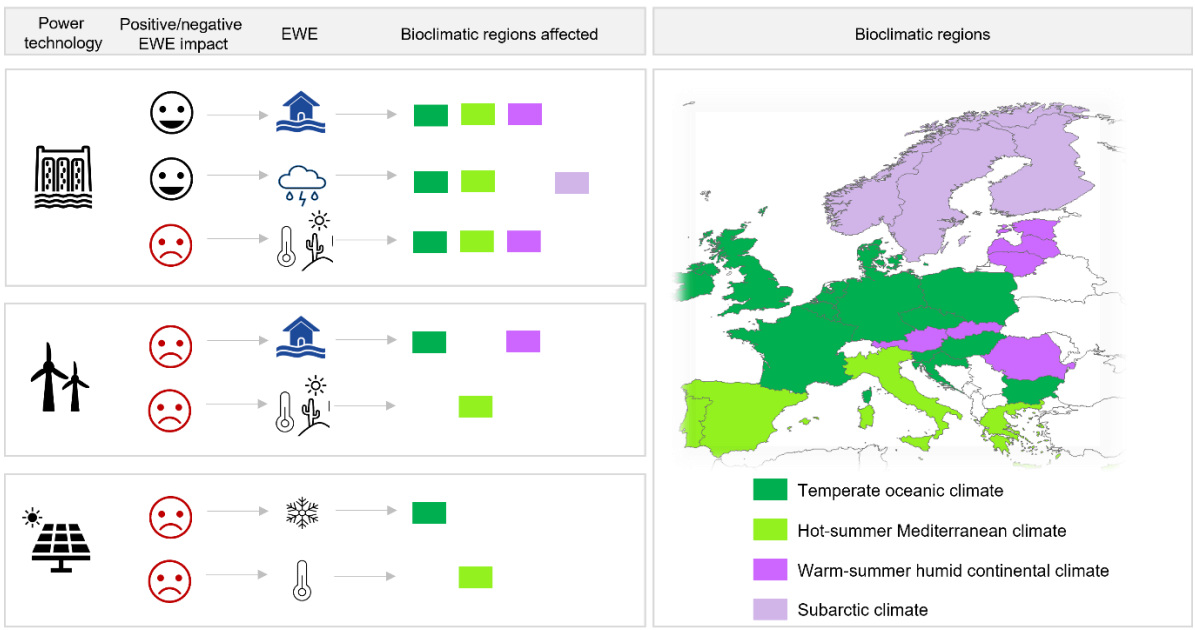
- **More recent floods and storms (2005-2016)** have a **higher impact on EU+ hydro**, **fossil**, and **wind power than older ones (1993-2004)**
- From 1993-2004 to 2005-2016 the **EU+ hydropower capacity factor tripled** during **flood years**, and **quintupled during storm years**, while fossil power plants decreased their power generation (CF) by about 1.5 times
- **Wind farms** are becoming **more vulnerable to floods**: recent flood years led to an almost **3-fold decrease** in wind power plants capacity factor than for older floods

- In the EU+, the installed capacity of wind power plants has been increasing, as well as their vulnerability to EWE. The **planning of new wind farms must consider the changing risks to power output due to EWE**

WHICH RENEWABLE POWER TECHNOLOGIES AND EU+ REGIONS ARE MOST AFFECTED BY EWE?

- **Hydropower** has been, on average, **positively affected by floods and storms across all EU+ bioclimatic regions**.
  - **Flood years:** Largest increases estimated in **warm-summer humid continental climates** (covering eastern European countries; +9.1% more than in years with no floods), **hot-summer Mediterranean climates** (Portugal, Spain, Italy, Greece, Cyprus, and Malta; +7.4%), and in **temperate oceanic climates** (remaining central European countries plus France and the United Kingdom; +6.2%)
  - **Storm years**: largest increases on hydropower capacity factors were in **Mediterranean countries** (+18.6% than in non-storm years)
  - **Droughts and heatwaves years**: -8.6%/-5.7% in hydropower in **Central Europe/ Eastern Europe**. Across time, each drought year brings cumulatively less -5.5% hydropower in the **Mediterranean**. **Southern Europe** is experiencing more intense and longer droughts due to a prolonged precipitation deficiency.
- **Wind power plants** installed capacity **is less used during drought and heatwave years across Mediterranean** countries. From one year with droughts or heatwaves to the following year, the wind capacity factor decreases -3% on average. Similarly, from one **flood year to the next,** the wind capacity factor decreases in **Central Europe** (-1.9%) and in **Eastern Europe** (-3.7%)
- **Solar PV** is **negatively affected by cold waves** in **Central EU+** (-4.5%). From one **heatwave year to the following one**, the **installed capacity of solar PV in the Mediterranean is less used by -3.7%** as very high temperatures cause an efficiency loss of solar panels [9], [10]

Representation of the impact of each EWE type on each power technology and per EU+ region



KEY TAKE AWAYS

This study **quantifies the impact of EWE on power technologies to understand how such impact has evolved over time and across European regions**

Future planning of the energy systems (i.e., definition of strategies towards an efficient use of water resources, planning of newly wind and solar farms), **must consider EWE impacts and disaster risk reduction strategies**. This would contribute to **improve the resilience of renewable energy supply** and to **define measures towards the cooperation between European regions during extreme weather episodes**

This policy brief is a result of the following scientific publication:

T. A. Brás, S. G. Simões, F. Amorim, and P. Fortes, "How much extreme weather events have affected European power generation in the past three decades?". *Renewable & Sustainable Energy Reviews. Volume 183, 2023, 113494, ISSN 1364-0321,* https://doi.org/10.1016/j.rser.2023.113494 .

DATA AND METHODS

National power generation data obtained from EUROSTAT [3], and records of EWE from EM-DAT, the International Disaster Data Base [7], all from 1990-2019

A time series statistical analysis based on superposed epoch analysis is used to quantify the impact of each type of EWE on different power technologies compared with non-EWE years. The quantification on how the impacts change over time is performed per power technology and per EWE type, and at the European and regional levels

This study has limitations that may underestimate the obtained results, such as the fact that the EWE have a short duration in time, which may make it difficult to detect an effect on power technologies, in particular when the CF is estimated at the annual level and the event impact as annual averaged. Some EWE may counteract the impact of other events occurring in the same year thus possibly underestimating the impact on each power technology. A seasonal and regional level analysis could improve the investigation of the extreme events impact, which is intended to be explored on further research

ADDITIONAL INFORMATION

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[3] EUROSTAT, "Energy Statistics," 2021. https://ec.europa.eu/eurostat/web/main/data/database (accessed Aug. 16, 2021).

[4] European Commission, "In depth analysis in support of the Commission Communication COM(2018) 773. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy." Brussels, 2018.

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[6] T. A. Brás, S. G. Simões, F. Amorim, and P. Fortes, "How much extreme weather events have affected European power generation in the past three decades?," *Glob. Environ. Chang.*, 2022, doi: Submitted.

[7] EM-DAT, "The Emergency Events Database - Universit´e catholique de Louvain (UCL) - CRED, D. Guha-Sapir. Brussels, Belgium," 2021. https://www.emdat.be/index.php (accessed Aug. 16, 2021).

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[10] M. T. H. van Vliet, L. P. H. van Beek, S. Eisner, M. Flörke, Y. Wada, and M. F. P. Bierkens, "Multi-model assessment of global hydropower and cooling water discharge potential under climate change," *Glob. Environ. Chang.*, vol. 40, pp. 156–170, 2016, doi: https://doi.org/10.1016/j.gloenvcha.2016.07.007.