ENERGY

TRENDS
ADAPTATION

Between the revival of fossil fuels and emergency sufficiency, the difficult process of adapting electricity grids

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The challenges of a changing climate are considerable for energy grids and infrastructure, which encounter difficulties in ensuring enough supply to meet demand during consumption peaks and times of reduced production capacities. In the United States, Europe, India, China and Brazil, the extreme weather events over the last year have highlighted the vulnerability of electricity grids. While gas, oil and coal offer a carbon-intense emergency solution to deal with shortfalls on the grid, the war in Ukraine has illustrated the cost of this dependence on fossil fuels in terms of strategic autonomy. Coupled with mitigation strategies, integrating adaption into transition scenarios and polices is now therefore more vital than ever.

DATA OVERVIEW

From summer 2021 to summer 2022: exceptional meteorological conditions that could become the norm

The 2021 report on the state of the global climate published by the World Meteorological Organization (WMO) shows an intensification of extreme events related to climate change. The average global temperature is 1.11 °C higher that during the pre-industrial era. Record temperatures were reached (54.5 °C in Death Valley, California, USA; 48.8 °C in Syracuse, Italy). In mid-August, Greenland was subject to exceptional glacier melting and, for the first time, rainfall was recorded at its highest point (3,216 m altitude) following several hours of temperatures above zero. Elsewhere in the world, flooding incurred colossal human and economic costs: 17.7 billion dollars for Henan Province in China, 20 billion dollars for Germany; due to drought, wheat and rapeseed production in Canada was 35% to 40% lower than in 2020. The year of 2021 also saw numerous population movements (internal migrations): over 1.5 million people displaced in China, more than 664,000 in Vietnam, and over 600,000 in the Philippines.[1] In Europe, the Copernicus program points out that during the three months of the summer of 2022, "*The average temperature for Europe from June to August 2022 was about 1.34 °C above the 1991-2020 average for the season. This is almost 0.4 °C higher than that recorded for the previous warmest European summer, which occurred just one year earlier, in 2021*". During August in particular, summer temperatures were up to "*1.72 °C higher than the 1991-2020 average*".[2] In France, the summer of 2022 was the second hottest recorded since 1900, with a difference of +2.3 °C compared to 1991-2020 averages. Three successive heatwaves in June, July and August totalled 33 extremely hot days (compared to 22 in 2003).[3] Official figures are not yet available from Santé Publique France on the number of deaths attributed to the heatwave, but the national statistics body INSEE nevertheless identifies an increased number of fatalities during that summer.

Extreme events like forest fires are increasingly frequent. Resulting from a combination of factors (mainly dry vegetation and soil, and higher temperatures), forest fires burn "*nearly twice as much tree cover today than they did 20 years ago*".[4] While the whole of the south of France was affected by numerous wildfires (61,921 hectares in 2022 against an average 9,117 from 2006-2021), the area of Gironde was hit hardest (over 26,000 ha burned). According to the European Forest Fire Information System (EFFIS), "*at least 901,094 hectares have burned in Europe, 750,000 of them in the EU*", with particularly high records exceeding all previous years: 293,155 ha in Spain, 149,278 in Romania, 103,382 in Portugal, etc.[5]

Climate change is destabilizing the natural balances maintained by a particular temperature or rainfall level. These modifications lead to extreme events and latent perturbations, with consequences for natural ecosystems as well as for the socio-economic activities and industries that they support. The energy sector is one of these, and is having to deal with more frequent, extreme, and intense climate events, coupled with energy demand that varies depending on the season and changes in the climate.

TABLE 1

SENSITIVITY OF THE MAIN ELEMENTS OF ELECTRICAL GRIDS TO CLIMATE HAZARDS

Source: Carbone 4, 2021

	Extreme heat Extreme cold Temperature fluctuations	Snow fall, floods	Violent winds/ storms	Forest fires
Power lines	○ Overheating or contraction (frost) of cables	◐ Damage to pylons and cables	● Damages to pylons and cables	◐ Heat, smoke and ashes can cut transmission lines
Transformers	● Diminishing capacity, accelerated ageing and rupture	● Short circuit (water infiltration) and explosion	● Short circuit (fall of objects) and explosion	● Destruction (equipment usually scarcely exposed)
Electrical substation (Circuit breakers…)	◐ Rupture, accelerated ageing	○ Breakdown, weakening and rigidification of insulations	◐ Short circuit (fall of objects)	● Destruction (equipment usually scarcely exposed)
Electronic equipment and telecomms	◐ Overheating or frost	● Damage linked to humidity or water infiltration	○ Damage (fall of objects)	● Destruction (equipment usually scarcely exposed)

○ Weak sensitivity ◐ Average sensitivity ● Strong sensitivity

THE OBSERVATORY'S LENS

Adapting energy grids is a multiple-choice question

The pressure of climate change on energy infrastructure and grids

The impacts of climate change, which include increasing temperatures, higher sea levels, greater frequency and intensity of precipitation, and extreme events, affect infrastructure and can destabilize all or part of the grid (**TAB. 1**), with a domino effect on: 1) other infrastructure in the energy grid,[a] and 2) other networks, such as transport (**FIG. 1**). These impacts affect production and operating capacities, the integrity and lifespan of infrastructure, and the stability of energy production and supply.

With the aim of improving resilience and adaptation of infrastructures to climate change while taking into account a key point that is rarely considered, i.e., the numerous interdependencies between the different networks (electricity, road and rail transport, and telecommunications, **FIG. 1**), France Stratégie recently suggested working on three focus areas.[6]

Provide shared references
- Make it easier for all actors to use the same set of climate forecasts
- Improve knowledge of the current state of grid infrastructure and their interdependencies

Establish national governance
- Create a working body gathering at least network operators and the State
- Establish in the law the production of a joint roadmap for adapting networks to climate change

Base the national vision on a local approach
- Suggest that local governments experiment with a system to establish a diagnosis and an action plan shared at local level
- Test out a system to bring feedback and capitalize on information within a national decision-making body

Therefore, increasing the resilience of energy infrastructure also involves different levers, as identified by Ouranos[b] in a report: better observe, forecast, and anticipate the impacts of climate change; modify climate norms; review the capacities and characteristics of physical installations; build climate resilience with inhabitants, etc.[7]

a Energy infrastructure concerns all of the physical installations that make up the energy grid. They play several roles: production, transport, supply and storage of energy. The grid thus form a network of more or less interconnected infrastructure.

b Ouranos is a Quebecois consortium on regional climatology and adaption to climate change.

TABLE 2

NON-EXHAUSTIVE TABLE OF CLIMATE CHANGE HAZARDS, POTENTIAL IMPACTS, AND RESILIENCE OPTIONS IN ENERGY SECTOR

Source: IISD, 2021

CLIMATE HAZARDS	EXAMPLES OF POTENTIAL IMPACTS (NON-EXHAUSTIVE)	EXAMPLES OF RESILIENCE OPTIONS (NON-EXHAUSTIVE)
TEMPERATURE INCREASE AND HEATWAVES	• Risk of failure of hydroelectric dams • Decreased efficiency of solar panels, thermal plants • Increased stress on the distribution system infrastructure	• Planning: Incorporate climate scenarios into load forecasts for future demand • Structure: Increase cooling system capacity • Monitoring and maintenance: More frequent maintenance and component replacement to reduce stress on the distribution system Enhanced dam safety monitoring management
CHANGES IN PRECIPITATION PATTERNS	• Water level fluctuations and drier soils can increase internal erosion of embankment dams • Inundation of coastal energy generation plants, substations	• Planning: Use up-to-date flood plain maps to locate new facilities outside high-risk flood zones • Structure: Reinforcing coastal infrastructures, adjust design criteria for transmission lines (height, materials…) • Monitoring and maintenance: Revise asset maintenance and replacement schedules
WINTER STORMS/ ICE STORMS AND HIGH-VELOCITY WINDSTORMS	• Ice build-up can result in snapped power lines, broken or fallen utility poles • Winds can bring down utility poles and transmission lines	• Planning: Install microgrids to enable communities to separate from failed central grids and run on secondary sources • Structure: Bury distribution lines • Monitoring and maintenance: Manage/trim the trees around transmission lines, use of smart grid technology to identify the precise location of failed or upcoming failure in distribution line…

For example, the Agence Parisienne du Climat, as part of its Adaptaville platform,[8] proposes adaptation solutions to deal with the risks of drought, flooding, and heatwaves, which can undermine the resilience of the capital's grid and energy supply. Solutions include producing local energy (micro-methanation of food waste from local communities), self-consumption (installation of green roofs with photovoltaic generation), and passive alternatives to individual air-conditioning (free cooling).

Nuclear power production strained by drought

Nuclear power plants are on the front line when it comes to climate change impacts and could be affected more than anticipated by forecasts.[9,10] The reason is that they require considerable quantities of water to cool down their facilities. Generally, plants withdraw water from rivers close by. The water is used to cool installations, and then discharged back into the river. Regulations limit the maximum temperature of water upstream from the power plant (e.g., 28 °C for the Garonne River at Golfech Power Plant); the maximum heating threshold of the river from upstream to downstream of the plant (e.g., +3 °C in summertime for the Rhone River at the level of Saint-Alban Power Plant); and a maximum threshold for water withdrawals (e.g., water consumption/evaporation is prohibited at the Chooz Power Plant if the flow of the River Meuse is under 20 m^3/s on average over 12 days).[11]

Periods of extreme heat and drought (which increase the risk of low waters) therefore heighten the risk of: 1) having insufficient water to cool power plants; and 2) reaching the regulatory limits, which threatens the activity of the power plants and the safety of infrastructure if they cannot be cooled down. In May 2022, particularly early compared to previous years, EDF was forced to slow down the activity of the Blayais Nuclear Power Plant located on the edge of the Gironde Estuary: the temperature of the river was too high and EDF could no longer discharge the water used for cooling, mainly to protect biodiversity.[12] RTE also insists on the location of nuclear power stations as a means for adaptation,[13] requiring not just a source of cold water nearby, but a location that limits the risk of submersion and tidal waves. Faced with these risks, Hervé Cordier, group leader of the engineering and new nuclear projects department at EDF, explains that, "*additional heat exchangers and air conditioning units have been installed at the plants [since 2003]*" adding that, "*work is underway at Gravelines Power Plant to raise the embankment and take account of sea levels*".[14]

BOX 1 • **EXPERIENCE FEEDBACK**

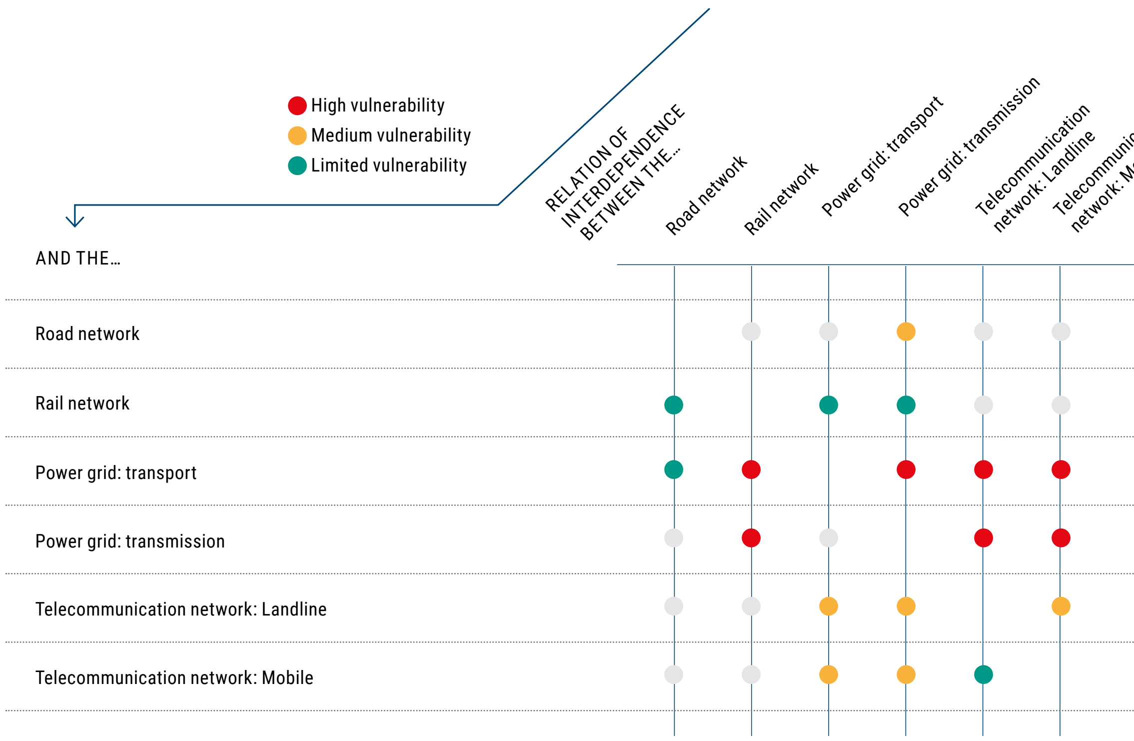
CHARACTERIZING THE IMPACTS OF CLIMATE CHANGE ON ENERGY INFRASTRUCTURE AND IDENTIFYING RESILIENCE OPTIONS: THE CASE OF CANADIAN INFRASTRUCTURE

The conclusions of a report by the International Institute on Sustainable Development (IISD) on the resilience of Canadian infrastructure recommend "*an integrated, whole-of- society approach to making infrastructure across Canada resilient to a changing climate*" in order to combat "*cascading failures*". Experts go on to suggest three categories of resilience: using assessment and monitoring tools; building in redundancy (emergency backup) systems; and structural modifications (Tab. 2), all of which should be informed by scientific knowledge on climate change observed and anticipated in the future.[15]

FIGURE 1

QUALITATIVE OVERVIEW OF INTERDEPENDENCIES BETWEEN NETWORKS

Source: France Stratégie, 2022



BOX 2 • **EXPERIENCE FEEDBACK**

ELECTRICITY SUPPLY MANAGED BY ENEDIS

The company ENEDIS, which manages the electricity supply grid in France is currently looking at the resilience of its infrastructure in the face of climate change impacts, such as "*severe climate events, storms, floods and heatwaves*", and also "*at transition events, like progressively rising temperatures and sea levels,*" (Nicolas Perrin, Director of CSR at Enedis).16 Adaptation avenues have emerged since the "wake-up call" triggered by the massive storm in December 1999 and the excessive heat of August 2003. The work in identifying major risks (storms, heatwaves, fires, rainfall, sticky snow) has led to the formulation of responses, like burying lines in wooded areas that are particularly sensitive to storms and wildfires; installing watertight apparatus in electricity stations; and installing pumps in flood risk areas. However, these responses still need to be improved because, for example, "*during heatwaves, the ground cools down less and therefore the heat loss from equipment underground is less effective.*"

Energy "sufficiency" is the new watchword for mitigation and adaptation policies

Energy sufficiency, although still not fully defined, involves controlling and reducing consumption and ranking uses and needs.[17] The concept undeniably calls for "*changing individual behaviour, economic frameworks and business models, with the aim of decoupling the creation of societal value and the consumption of resources/energy*".[18] In the face of threats weighing on the grid and on the production and operating capacities of energy infrastructure, taking up energy sufficiency or conservation practices constitutes a strategic approach, in particular in these times of geopolitical tension.

Numerous countries have recently unrolled their "energy conservation plans" in order respect the European target to reduce electricity consumption by 10% by March 2023 and by 5% during peak demand. European states, which remain free to choose which measures to adopt, have established solutions like incentives to reduce heating in households (-1 °C in Italy) and a drop in the maximum temperature threshold (19 °C in public buildings in Italy, France and Spain; maintaining buildings at 16 °C or 17 °C during the weekend in Lithuania); postponing the start of the heating season (two weeks later in France, not before November in Italy); reducing temperatures at sports facilities (gymnasiums, municipal swimming pools), and the use of hot water in offices; turning off lights during the night for some monuments and shops after closing time (Portugal, France), and from 10 pm in Spain; restrictions for Christmas lights; the extension of teleworking; and regrouping of public services in adapted premises to limit the heated surface area, etc.

Beyond Europe, other countries are also encouraging energy conservation. In June 2022, the Japanese government – struggling with rising summer temperatures and a plummeting yen that had contributed to increasing the cost of energy imports – called on inhabitants and companies to act more ecologically (turning off lights in unoccupied areas, reducing the use of televisions by an hour a day, turning off heating of toilet seats, etc.) in order to reduce energy consumption and avoid cuts.[19,20] These rapid conversions subject to constrained circumstances akin to "state energy conservation" fit into a defined, limited timeframe and are very different from integrating energy sufficiency into long-term transition scenarios. The CACTUS project,[21] driven by the French association négaWatt and the German research institute Fraunofher ISI, is one initiative that encourages such integration into transition scenarios, such as by training energy and climate policy actors in Hungary and Lithuania between 2020 and 2022.

Heatwaves and pressure on the grids

Increasingly frequent heatwaves are encouraging inhabitants of numerous regions in the world to change their behaviour and install air-conditioning. Yet the rising use of air conditioning causes a local increase in night-time temperatures that has negative impacts on the comfort and health of inhabitants and could create a negative feedback loop, with increased temperatures pushing for the use of even more air conditioning, and vice versa.

According to the International Energy Agency, about 2.27 billion air conditioning units were in operation in the world in 2021, which represents about 16% of global electricity consumption.[22] Forecasts show that "*the global stock of air conditioners [is likely to rise] by over 50% during the next decade*": the threshold of four billion appliances in service in the world will probably be reached in 2040. While currently China and the United States make up most of demand, the biggest-growing markets will probably be India and Indonesia, "*where the number of units in service is expected to be multiplied by respectively fifteen and eight from 2020 to 2040*". In France in 2020, the number of air conditioning units sold "*exceeded 800,000 units compared to only 350,000*" in 2019. Twenty-five percent of households were equipped with air conditioning in 2021, compared to only 14% of households in 2017.[23,24]

As a direct consequence of the increase in electricity needs during excessively hot periods, some States are obliged to make emergency changes to their energy mix, to the detriment of GHG emissions reduction targets. For example, in spring 2022, India and Pakistan were confronted with an unprecedented heatwave with temperatures reaching 43.5 °C in New Delhi in the end of April and up to 48 °C in parts of the rural area of Sindh, which is +8 °C higher than the seasonal average. On 26 April, India reported record national electricity consumption levels (204.65 GW),[25] following a 12% increase in energy demand that month. To cope with this increased demand, the country relaunched coal production (the country's main energy source) and set up rationing (cuts in some factories, reduction in industrial activity, etc.).

In China, in particular in the Sichuan province, temperatures exceeded 40 °C several times during the month of August 2022. Faced with the almost-systematic use of air conditioning by the province's 84 million inhabitants and with dried-up rivers (Sichuan depends on hydropower for 80% of its electricity), the government imposed electricity rationing on professionals, and the China Internet Network Information Center[c] reported that, "*the quantity of coal used to operate electricity power plants increased by 15% in the first half of August, compared to the same period*" in 2021.[26]

Influence of climate change on national energy choices

Wind power production depends on a number of factors, such as speed, intensity, direction, windshear and wind direction, the amount of cloud cover, and the transmission capacity of the atmosphere. Slower wind speeds[27,28,29] have been observed in several places around the globe, with greater changes than average at local level, such as in the north of China ("*in Inner Mongolia and in the Gansu, the two best-equipped provinces, the wind potential has dropped by about 15% since 1979*")[30] and in the United Kingdom (the wind power sector only supplied 7% of electricity in September 2021, compared to 24% usually in the same period, which led the country to restart a coal power plant).[31] French start-up Callendar, which specializes in evaluating climate risks, also confirms this trend in France, where wind speeds were abnormally low in September 2021. At the scale of the Hauts-de-France region, the average wind speed was 58% lower than normal speeds from 1991-2020 for the month of September, bearing in mind that a quarter of the country's wind farms are located in this region.

For solar power, forecasts clearly show an increase in the degree of solar radiation, but it appears that solar panels produce smaller yields in periods of high temperatures.[32,33]

Water stress: a major challenge for hydropower facilities all over the world

The potential for hydropower is directly related to the availability of water. A changing climate will therefore affect the production capacity of hydropower plants (modification of natural inputs feeding into the reservoir lake upstream in terms of both time and quantity, higher air temperatures, early snow melts, reduction of precipitation in the form of snow) and energy demand (modification of demand peaks according to temperature variations). For multi-usage reservoirs, other activities that require water can be impacted and enter into greater competition with hydropower.

The heatwaves of the summers of 2021 and 2022 caused numerous rivers around the world to dry up. In South America, the Parana River (second largest river on the continent) lost six metres in two months, reducing hydropower production. Due to insufficient supplies, Brazil turned to the United States to import gas, the price of which rocketed around the world. In China, a heatwave hit the southwest of the country (up to 43.3 °C in Chengdu). The level of the Yangtze River was 40% below normal over the summer. During the summer of 2022, like 2021, the authorities were forced to cut electricity supplies to some industrial sites (Toyota, Foxconn, Contemporary Amperex Technology Co., Limited – CATL), as well as steelworks and other metal foundries, which had to interrupt their activities, some of which are strategic for the ecological transition, such as the manufacture of solar panels. In Italy, the River Po reached a historically low level during the

c Official State-run web portal.

summer of 2022 and hydropower reserves were 40% below the historical average for the same period **(FIG. 2, UPPER PANEL)**. Hydropower represents about 35% of the total production of green energy, and usually meets over 15% of Italian energy demand. The same trend can be observed in Spain, where hydropower production was over 30% lower during summer 2022 compared to its average of the last seven years **(FIG. 2, LOWER PANEL)**.[34]

This pressure on water resources due to low levels of precipitation and higher temperatures can generate situations of conflicts of use when a river supplies different activities in the same geographic area. For example, the hydropower system on the Durance River is one of the most engineered in France, and provides 3.5 million inhabitants with drinking water (in the Bouches-du-Rhône and Var areas); it also provides water to farms and manufacturers in the region. Overall, the Durance and its tributary the Verdon produce 50% of regional electricity and 10% of national hydropower. In 2022, EDF had to reduce its production starting from the month of February, and by up to 60%, to maintain enough water for other uses judged to be a priority.[35]

Nevertheless, the development of renewable energy remains a key driver of the energy transition, and of national energy independence vis-à-vis the exterior, and local resilience. In Benin, the United Nations Development Program supported a project to bolster the resilience of the energy sector against the impacts of climate change in order to reduce the vulnerability of urban and rural communities, at every stage of the energy grid (production, transport and energy supply). The project led to the installation of mini solar power stations, solar lampposts, and the rehabilitation of an electricity station with the acquisition of a smart electric transformer.[36]

BOX 3 • **EXPERIENCE FEEDBACK**

THE AMERICAN GRID UNDER PRESSURE

In the United States, a combination of several factors (relating to climate, in particular the sharp rise in heatwaves; the economy, marked by a big shortfall in investment in infrastructure; behaviour, with an increase in electricity demand; and structure, with aging infrastructure that are therefore more vulnerable to the impacts of climate change) has led the country into a complex situation involving increased pressure on an aging grid of energy infrastructure.

It is known that "*climate hazards are the main cause of blackouts in the United States. In total, 679 system-wide outages occurred from 2003 to 2012 due to climate conditions*". Thus, American infrastructure and in particular power transformers need renewal. For example, Superstorm Sandy (2012) "*provoked the explosion of a power transformer operated by the company ConEd, contributing to a blackout that deprived over 8.1 million households and companies in and around New York of electricity, 800,000 of them for 10 days*".[37]

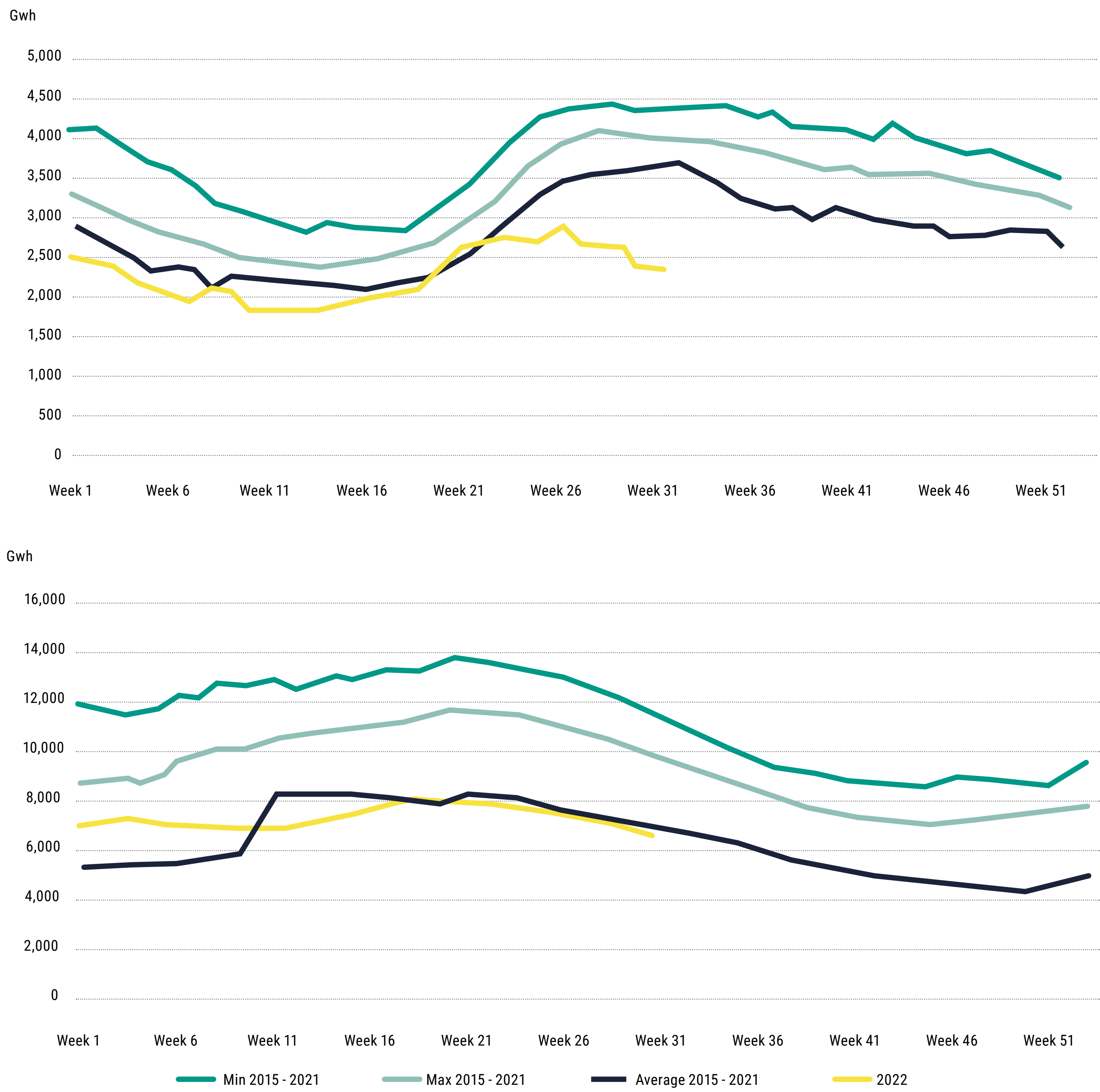
During the last two years, the United States has been confronted with increasingly frequent heatwaves; the population reacts by increasingly turning to air conditioning: the surge in electricity demand could result in higher energy costs[38] and significant risks of electricity cuts.[39] California appears to be particularly vulnerable to these risks, as was the case in early September 2022.[40,41] The Californian government launched the FlexAlert measure (created by the non-profit operator California ISO) and disseminated energy-saving tips to avoid saturating the grid, like avoiding setting air conditioning lower than 25 °C, limiting the use of electric devices, and turning off unneeded lights.

In early summer 2021, an unprecedentedly hot heatwave (up to 51 °C) affected the electricity grid and infrastructure in the city of Portland, Oregon (some cables melted, trams stopped running, the grid was saturated by increased use of air conditioning, etc.).

FIGURE 4

UPPER PANEL: HYDROPOWER RESERVES IN ITALY; LOWER PANEL: HYDROPOWER RESERVES IN SPAIN

Source: Schroders, 2022



KEY TAKEAWAYS

The energy market crisis has highlighted how exposed energy grids and infrastructure are to intensifying climate change. Although attention tends to focus on the war in Ukraine that began in February 2022 as a driver of inflation, the direct and indirect consequences of drought, flooding and heatwaves indicate that the conflict could hide more structural challenges arising from climate change. With a combination of demand peaks caused by air conditioning, the drying-up of hydropower production capacities, and water shortages for cooling down power plants, repeated heatwaves have accentuated several points of tension affecting the electricity grid. Aging infrastructure, concentrated production capacities, and insufficient anticipation of adaptation requirements are among the causes of grid vulnerability on infrastructural and organizational levels. The observation of global phenomena, like the slowing down of windspeeds (stilling), also involves new risks for renewable production that have been little studied to date. When it pushes up the demand for energy, "maladaptation" itself becomes a factor in destabilizing the grid.

Two main response models emerged in 2021 and 2022. Firstly, the emergency use of fossil fuels, which are more flexible, to take over from renewable production capacities affected by climate variables, underlines the fact that ill-prepared adaptation can clash with mitigation strategies. In addition, the war in Ukraine brings a reminder of the geostrategic cost of such a dependence on fossil energy. As a result, accelerating the transition of the energy mix towards low-carbon energy sources is clearly a keystone in the strategy to adapt production networks in order to guarantee supply and strategic autonomy for States and non-state actors.

Next, the sudden propulsion of "energy sufficiency" to the top of the political agenda, in the form of emergency plans driven by States, opens up new horizons for directing demand in transition scenarios. The long-term consequences of energy conservation will be apparent in the years to come: will it become a key feature of mitigation policies, reducing the pressure generated by climate change on energy infrastructure, or will its emergency adoption without prior planning have a rebound effect on energy demand?

In any case, the adaption of energy actors and infrastructure requires adopting a holistic, ecosystem approach to energy issues in order to better control the domino effect (on a network or between different networks) and conflicts of use in the case of diminishing resources. On the other side, integrating data and long-term climate forecasting into the planning, sizing and operation of energy infrastructure is clearly crucial in order to anticipate the impacts of climate change on energy infrastructure and grids as soon as possible.

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