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The European Electricity Supply System in Transition

And possible consequences of a major European disruption ("blackout")

Summary: The European electricity supply system is undergoing a fundamental transformation. Many steps are taking place in parallel and seem to be poorly coordinated and harmonized. However, a system is always more than the sum of its parts. Due to the numerous changes and their interdependencies, these processes of change also increase the danger of major disruptions, up to and including a possible supra-regional power blackout. However, the consequence would not only be a large-scale power blackout. It would inevitably trigger chain reactions in the entire supply logistics that are hardly assessable and for which neither the people nor the companies nor the state and its organs are prepared. This article examines the far-reaching upheavals in the European power supply system and the possible consequences of a blackout.

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1 Current challenges in the European interconnected system

The European transmission grid of the Central European Regional Group (ENTSO-E/RG CE) comprises 29 countries and stretches from Portugal to the east of Turkey, from Sicily to Denmark and, since March 2022, also to eastern Ukraine. It represents a functional unit that only works as a whole. Disruptions in this system can potentially spread over a large area, even if corresponding safety mechanisms are implemented to prevent this. In addition, there is networking with the neighboring network regions. The European Network of Transmission System Operators for Electricity (ENTSO-E) has 39 members from 35 countries.[1]

The European power supply system is undergoing fundamental change as a result of the energy transition. Many steps are taking place in parallel and seem to be insufficiently coordinated and harmonized. This contri-bution tries to work out the multilayered interrelationships and in the sense of: Only who knows and under-stands the whole, also understands the details and not vice versa [cf. Meadows et al. (1973)].

Even though this is already a fairly comprehensive consideration, it is not complete. And as is often the case in complex environments, contradictions and conflicting goals arise [see chapter "The Dark Side of Digitalization"], which cannot all be dealt with here. The main objective is to highlight those aspects and interrelationships that pose a threat to system and supply security. This is also intended to highlight the increasing fragility of the European interconnected system.

1.1 Permanent balance

In an alternating current system, the balance between generation and consumption must be maintained continuously for 31.5 million seconds per year, with a relatively small tolerance. If this balance cannot be maintained, the system threatens to collapse. It is therefore a very delicate balance, of which we are often not aware.

It is problematic that in many current considerations of the energy transition, only annual balances and average values are considered and presented, which is clearly too short-sighted and dangerous for the immediate system security.

This balancing act was comparatively easy to maintain in the previous large-scale system with a few thousand easily controllable large-scale power plants. The constantly fluctuating consumption could be balanced out well. With the energy transition, however, the number of volatile, barely controllable generation plants is increasing dramatically, while at the same time the availability of controllable power plants is decreasing. Instead of a few thousand power plants, there are now millions of plants, which additionally significantly increases the complexity of the overall system and changes the system behavior [cf. chapter “The Dark Side of Digitalization”] and [cf. Erlhofer (2023). chapter 6].

1.1.1 Reduction of the system-critical instantaneous reserve

Until now, the synchronous generators of the large power plants that generate electricity have been an essential guarantor of the very high system stability in the European interconnected system. Their rotating masses ("instantaneous reserve")[2] represent an inherent energy store that can compensate for short-term energy surpluses or deficits. They are a kind of "shock absorber".

The synchronous generators produce the frequency of the alternating current, which in turn expresses whether there is a power shortage or a power surplus in the overall system. Via the frequency, control interventions take place fully automatically and purely according to the laws of physics, which permanently balance the entire system and keep it stable. It's like walking a tightrope, where the balance must be constantly maintained by barely visible balancing measures. Any hectic reaction can be dangerous and lead to a crash.

With the energy turnaround and the associated shutdown of conventional power plants, there is also a strong reduction in these system-relevant shock absorbers. Photovoltaic (PV) and wind power plants (WPP) do not have this central system function. In the case of wind power plants, there are rotating elements, but no direct coupling, since wind power plants have a direct current generator due to the changing wind speeds. The direct current generated is converted by downstream inverters and only then fed into the alternating current grid.

1 Cf. https://www.entsoe.eu/about/inside-entsoe/members. Accessed on 23.10.2023.

2 Cf. https://www.saurugg.net/hintergrundthemen/#momentanreserve. Accessed on 23.10.2023.
Numerous footnotes refer to sources on the author's website (www.saurugg.net). The background is that the author has been providing comprehensive evaluations and summaries on his website since 2011, which usually refer to more than one source. Since the author works mainly in German-speaking countries, many sources also refer to German-language articles and authors.

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Although there are considerations to use the existing generators as flywheel masses, this often requires extensive conversion measures and causes additional costs for which there are no regulations so far. Replacement solutions with large battery storage units and power electronics have yet to be realized on a large scale. But even they will not be able to completely replace synchronous generators from today's perspective.[3] [4]

On the other hand, the regional distribution of the instantaneous reserve and the individual size of the respective plants also play a role. In northern Germany and Denmark, for example, there are hardly any conventional power plants and thus little instantaneous reserve. In the event of an unfavorable grid failure with a separation into sub-grids or a major disruption, a far-reaching domino effect could be triggered. A network reconstruction also becomes very problematic with little or insufficient instantaneous reserve [cf. Reichl et al. (2015)], as the expected load peaks can only be balanced with difficulty, which in turn can lead to considerable damage to (IT) infrastructures if large voltage and current fluctuations occur. On the other hand, the physical size of the respective instantaneous reserve also affects the fault tolerance of the overall system [cf. Qvist et al. (2023)].

Therefore, fewer and fewer plants will contribute to system stability in the future. This increases the fragility and susceptibility to faults of the interconnected system. From a purely technical point of view, it would be possible to achieve much more than is currently being strived for and implemented. The reasons for this are complex and range from a lack of overall systemic understanding to purely economic considerations.

1.2 Insufficient systemic implementations

In addition, there are several individual issues that are often only considered in isolation. However, a system transformation requires a holistic, systemic and coordinated implementation of the necessary measures if it is to be successful.

Many individual construction sites without sufficient assessment of the side effects and consequences form the basis for failed projects, of which there are quite a few, especially in Germany. However, the restructuring of the energy supply is of a completely different order of magnitude than, for example, the construction of a major airport or the maintenance of the road or rail infrastructure. Not to mention the fact that the conversion has to take place during ongoing operations, which is often compared to open-heart surgery.

1.2.1 Market liberalization ("unbundling")

A central cause for many unsystematic actions and for the lack of understanding of the system can probably be traced back to the EU market liberalization ("unbundling"). In the process, the holistic view in the form of energy supply companies that had been cultivated until then was broken up into several sub-areas: the power plant operators, who now have to work profit-oriented, the grids, which are regulated due to their natural monopoly position, and the electricity market and distribution, which formally delivers the electricity to the customers. Trading and distribution should no longer have anything to do with physical reality and infrastructure. Therefore, each sector is called upon to take care of its own optimization. Although this brings some efficiency gains, it also has serious side effects. If everyone only pays attention or has to pay attention to their own technical and financial optimization, the common ground is lost and otherwise possible synergies and opportunities for compensation have to be bought at great cost. As is so often the case, the side effects only appear with a time lag [cf. chapter "The Dark Side of Digitalization"] and [cf. Erlhofer (2023). chapter 6].

Market liberalization was started more than 20 years ago with the best intentions to break up the old and rather inflexible monopolies of the large energy supply companies, to lower prices and improve service. This has more or less succeeded since then. Only the future will show whether this was really sustainable. At any rate, there are justified doubts at the moment, as the explosion in electricity prices in recent years has shown, for example. In a short timeframe, a large part of the savings that had previously been achieved for the customers were eaten up again. The causes, however, were not only the war in Ukraine and the increased gas prices, as is often claimed, but a shortage of reliably available resources, which was already announced with the price increases from spring 2021.[5]

3 Cf. Stabilising US power grids using synchronous condensers. https://watt-logic.com/2023/09/14/synchronous-condensers-in-the-us. Accessed on 23.10.2023.

4 Cf. Overview of frequency control techniques in power systems with high inverter-based resources: Challenges and mitigation measures. https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/stg2.12117. Accessed on 23.10.2023.

5 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#strompreise. Accessed on 23.10.2023.

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Over the past 20 years, a large part of the previously existing surpluses in power plant capacities have been continuously reduced within the framework of market liberalization. The regulatory requirements for savings in grid operation have led to a situation where there are hardly any reserves available and parallel to the necessary further expansion, the renewal of the existing infrastructure is becoming more and more urgent.

These economic optimizations have also led to the fact that many resources such as power plants or new battery storage systems have been optimized primarily to achieve maximum yields and can therefore no longer behave in a way that serves the system per se.

In addition, more and more niche providers are entering the market to take on individual, lucrative tasks. In principle, a certain degree of competition can be a driver of innovation. But what is also often overlooked here is that it creates other problems and side effects. For if the existing players are cannibalized, the question arises as to who will take over the non-profitable areas. For example, a lot of money can be earned today and in the future with large battery storage systems in the provision of balancing energy, as high cycles are also required here. This means that systems that were previously able to provide not only balancing energy to compensate for unforeseen power fluctuations, but also continuous energy to secure the base load, are becoming increasingly uneconomical and thus less attractive. Both systems are absolutely necessary to be able to guarantee system security at all times. It is therefore foreseeable that without balancing regulation, the general public will ultimately be left to bear the high costs of the uneconomical but nevertheless necessary systems. These costs are often hidden behind the grid fees. This shows once again that either-or thinking does not contribute to solving the problems at hand. Instead, cooperation is an essential prerequisite for a functioning and affordable energy supply.

A simple but presumably very effective regulation could be that market participants of a certain size have to fulfil certain quality requirements, e.g. they have to be able to reliably supply electricity for a number of hours a year to be defined (band energy or base load), otherwise considerable compensation payments become due. The whole thing could well be coupled with a certain CO2 budget. This would foreseeably force cooperation and the financial compensation would presumably be much cheaper than today, where the general public has to pay for the expensive compensation measures.

1.3 Power trading

Electricity trading is also playing an increasingly critical role. In June 2019, for example, German electricity traders put the electricity supply system in a precarious position by exploiting a regulatory loophole. Despite warnings and now looming heavy fines, loopholes are likely to continue to be exploited.[6]

In 2020, 141, in 2021 248, in 2022 210 and in 2023 until September 187, larger frequency anomalies were observed, especially around the hour change,[7] which are predominantly due to operationally optimized power plant deployment planning.[8] To compensate for these deviations, half to two-thirds of the reserves held for unplanned power plant outages are regularly misused. Although it is technically possible to remedy this situation, the necessary regulation has not yet been implemented. If additional power plant outages occur during this period, which is expected to happen at the timetable change[9] is more likely, this could trigger a serious domino effect.

In addition, electricity prices in Europe have risen significantly since autumn 2021. While the average price for a megawatt hour (MWh) of electricity on the electricity exchange was around 35 euros in the period from 2015 to 2020, this rose to 97 euros in 2021 and even to 237 euros per MWh in 2022 for the German electricity market. By September 2023, the average price was 100 euros per MWh, with two extreme outliers: On 2 July 2023, the extreme value of -500 euros per MWh was reached for the first time, meaning that large-scale consumers received 500 euros for purchasing electricity for which they would otherwise have had to pay around 100 euros. On 11 September, the highest value for the year to date of 524 euros per MWh was reached, while just 30 hours earlier electricity was still being given away for 0 euros.[10] With the further expansion of volatile generation without sufficient storage facilities, such high fluctuations will occur more and more frequently

6 Cf. https://www.saurugg.net/2020/blog/stromversorgung/gier-frisst-hirn-und-kann-in-die-katastrophe-fuehren. Accessed on 23.10.2023.

7 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#netzfrequenz. Accessed on 23.10.2023.

8 Cf. https://www.amprion.net/Netzjournal/Beitr%C3%A4ge-2021/Ph%C3%A4nomen-zur-vollen-Stunde.html. Accessed on 23.10.2023.

9 The transactions for the purchase and sale of electricity quantities arising from electricity trading, both within and across control areas, are regulated by "schedules" that must be registered with the TSOs.

10 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#strompreise. Accessed on 23.10.2023.

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within a day, or even over several days. The basic problem here is also the optimization of individual parts.[11] In addition, the expected high returns can lead to additional speculation. This not only increases costs, but also endangers grid stability.

At the same time, supra-regional electricity trading because of to the EU regulation on the internal electricity market,[12] be significantly expanded by 2025. To this end, at least 70% of the technically possible transmission capacity at the cross-border interconnection points must be made available for electricity trading, which means a considerable expansion compared to previous practice. These cross-border interconnection points were never designed for such extensive electricity trading and transport, but only served as fallback levels.

What leads to a more efficient use of resources in everyday life can quickly lead to large-scale power cuts in the event of a disruption. The lack of substructures with reserves and redundancies increases the fragility of the system [cf. Vester (20118); Taleb 2013; Dueck (2015)]. See also the section on major disruptions as possible warning signals below.

The desire of politics and the electricity trade for a "European copper plate"[13] is understandable but lacks any reality and ignores physical framework conditions and laws.

1.3.1 Merit order principle

Electricity trading on the electricity exchange is based on the so-called merit order principle. The order in which the power plants are used at an electricity trading point is determined in such a way that the best economic electricity price is achieved. Power plants that can produce electricity very cheaply are connected to the grid first. Then power plants with higher marginal costs are switched on until demand is met. The last power plant required determines the price for all the generation plants that are added. The merit order therefore does not consider any fixed or system costs, but only the pure generation costs.[14]

Over the past 20 years, this principle has led to a much more efficient use of power plants and a consistent reduction of seemingly unnecessary and actual overcapacities, which has also led to a reduction in costs. In addition, renewable generation plants (RE) with very low marginal costs push down the price of electricity. However, this is more a case of concealment. This is because the subsidized RE plants receive a significantly higher remuneration within the framework of the apportionment procedure than they generate themselves. On the other hand, the necessary compensation measures for schedule deviations are hidden in the grid charges and passed on to all end customers.

Moreover, this model seems to have considerable design flaws, which became particularly serious in the context of the 2022 energy crisis. If the marginal costs of the last required power plant rise massively, e.g. due to a sharp increase in the price of gas, the entire electricity price rises massively and all other power plant operators, who operate with significantly lower production costs, reap enormous windfall profits. This is why this model also came under massive criticism in 2022 and would have to be reformed, something of which nothing has been heard so far. It can therefore be assumed that such outliers will continue to be possible and to be expected.

Another design flaw is likely to be reflected in rising electricity prices as early as 2021. While this model led to significant increases in efficiency in times of massive overcapacities, now with less and less reliably available power plant capacities, and because of the high volatility of RE, this leads to a shortage situation in which the price can be artificially driven up [cf. Dueck (2015)]. This can lead to an extreme situation in which unavailable energy can no longer be replaced, even at a high price. In the final analysis, large-scale power cuts would be necessary to prevent a system-threatening shortfall.

The pure focus on marginal costs is therefore clearly inadequate and will foreseeably lead to more and more extreme outliers. The losers, as is so often the case, are the consumers, who will always have to foot the bill in one form or another. So once again it is true that only those who know and understand the whole also understand the details and not vice versa [cf. Meadows et al. (1973)].

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11 Cf. Die Uhr tickt: Warum es dringend eine Gesetzgebung für Batteriespeicher braucht. https://www.pv-magazine.de/2023/09/11/die-uhr-tickt-warum-es-dringend-eine-gesetzgebung-fuer-batteriespeicher-braucht. Accessed on 23.10.2023.

12 Cf. Verordnung (EU) 2019/943 des Europäischen Parlaments und des Rates vom 5. Juni 2019 über den Elektrizitätsbinnenmarkt (28). https://eur-lex.europa.eu/legal-content/DE/TXT/HTML/?uri=CELEX:32019R0943&qid=1694768460571. Accessed on 23.10.2023.

13 An ideal European electricity system, in which electricity costs the same everywhere and there are no transport bottlenecks, in which electricity producers and electricity consumers can generate and consume electricity without restrictions, is compared to a gigantic copper plate. The market design in the electricity sector is built on this fantasy. This causes a high demand for constant corrective measures (redispatch).

14 Cf. Was bedeutet Merit-Order?. https://www.next-kraftwerke.de/wissen/merit-order. Accessed on 23.10.2023.

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In addition, this market model cannot be changed so easily, since it has meanwhile reached such a high level of complexity that no one really knows what will happen if one intervenes here. One could therefore well conclude that the jug must go to the well until it breaks. One could just as well speak of a "system too big to fail" here.

1.3.2 Lack of electricity agreement with Switzerland

In addition, there is also a political dispute between Switzerland and the EU.[15] With the expansion of the electricity market and the increase in the international exchange of electricity, there is no way around Switzerland. With 41 cross-border interconnectors, no other country has as many electricity grid connections to neighboring countries as Switzerland. Switzerland thus plays a central role in the exchange of electricity in Central Europe. Due to the lack of a comprehensive agreement between the EU and Switzerland, a separate agreement on electricity was also rejected.

This means that Switzerland will in future be excluded from committees and the exchange of information on electricity trading. At the same time, the Swiss transmission system operator Swissgrid would then have to balance out any load flows via Switzerland that might occur unexpectedly as a result of international electricity trading.[16]

This already led to a critical situation in 2019.[17] Since the flow of electricity follows purely physical laws and takes the path of least resistance, regardless of between whom the electricity was previously traded, there can be significant unplanned load flows across Switzerland. This is an additional factor that increases the risk of a major disruption across Europe.[18]

1.4 Insufficient systemic implementations

However, a lack of systemic implementation can also be observed in many other areas. It is not the knowledge or the necessary technology that is lacking, but the understanding and the concrete implementation. Conflicting goals of different actors probably also play a role.

The problems are complex and often start from the fact that the installation of wind power and photovoltaic systems alone is not enough, even if this is the top priority in many countries. For a successful energy transition, the entire infrastructure must be adapted and expanded, something that has been insufficiently addressed, ignored or postponed so far.[19] [20]

1.4.1 Reliably available power plant capacities

In recent years, Germany in particular has done everything in its power to phase out coal and nuclear energy as quickly as possible. At the same time, little attention was paid to the implementation of the necessary replacement measures. While the phase-out of nuclear energy has been completed meanwhile, the phase-out of coal must now be reversed and the return to coal must be carried out. Without rotating masses and quickly deployable replacement power plants, such as gas-fired power plants, the coal phase-out will not succeed either.

Large-scale battery storage could take over part of it, but it only has plants that can stand in for a few hours. In Germany, several large-scale battery storage facilities are currently being planned, built or partially completed. Depending on how one looks at it, between 23 and 43 GW of capacity would have to be added from gas-fired power plants in Germany by 2030.[21]

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15 Cf. Niederlage vor Gericht für Swissgrid. https://www.srf.ch/audio/info-3/niederlage-vor-gericht-fuer-swissgrid?id=12441910. Accessed on 23.10.2023.

16 Cf. Stromabkommen EU-Schweiz. https://www.saurugg.net/2019/blog/stromversorgung/stromabkommen-eu-schweiz. Accessed on 23.10.2023.

17 Cf. Netzsicherheitsverletzung vom 20. Mai 2019. https://www.swissgrid.ch/de/home/newsroom/newsfeed/20190524-02.html. Accessed on 23.10.2023.

18 Cf. Ungeplantes im Stromnetz – ein Risiko für die Schweiz. https://www.swissgrid.ch/de/home/newsroom/blog/2023/ungeplantes-im-stromnetz.html. Accessed on 23.10.2023.

19 Cf. Netzbetreiber Amprion warnt: Rascher Kohleausstieg belastet die Versorgungssicherheit. https://www.handelsblatt.com/politik/deutschland/energiewende-netzbetreiber-amprion-warnt-rascher-kohleausstieg-belastet-die-versorgungssicherheit/27867444.html. Accessed on 01.10.2023; oder SuedLink: Der Elbtunnel für die Stromautobahn https://www.ndr.de/nachrichten/schleswig-holstein/SuedLink-Der-Elbtunnel-fuer-die-Stromautobahn,suedlink298.html. Accessed on 23.10.2023.

20 Cf. Eon-Chef warnt vor kontrollierten Stromabschaltungen. https://deutsche-wirtschafts-nachrichten.de/517630/Eon-Chef-warnt-vor-kontrollierten-Stromabschaltungen. Accessed on 23.10.2023.

21 Cf. Ohne Gaskraftwerke kein Kohleausstieg? https://www.tagesschau.de/wirtschaft/deutschland-braucht-neue-gaskraftwerke-101.html. Accessed on 23.10.2023.

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That alone would be an enormous challenge. However, the war in Ukraine and the interruption of gas supplies from Russia call these projects into question. Quite apart from the fact that infrastructure projects of this magnitude cannot be realized overnight, any delay and the lack of an adequate replacement would have to throw all other plans out the window, which is hardly the case so far. One-sided goals are stubbornly adhered to without adapting them to the constantly changing framework conditions.

Even the announced expansion of nuclear power in France is only a declaration of intent for now,[22] which has already changed several times in recent years. The average age of French nuclear power plants is 36 years.[23] With a current construction period of 10 to 15 years, it is therefore not a question of expansion, but only of replacing old plants, which already have to be taken off the grid more and more frequently for safety reasons.

The expansion of renewable generation plants also tends to be severely delayed, although here there is a clear trend reversal in the area of PV plants by 2023. But while PV plants can be installed relatively quickly, the necessary grid and storage infrastructure often fails.[24] More and more projects can no longer be connected to the grid. Overproduction has to be shut down more and more frequently to prevent grid overload.[25] All this causes ever higher costs, which have to be borne by the end consumers through the various levy systems.

In addition, Germany is increasingly giving away cheap surplus electricity abroad or even paying for the purchase and having to buy back the missing electricity at other times. This is not only a disastrous development from an economic point of view, but also leads to an increasing burden on the infrastructure. Such developments can now be observed in more and more countries, especially in the Netherlands, Belgium and Spain.[26]

It has also been pointed out for years that without new subsidies, many German wind turbines can no longer be operated economically or have to be dismantled due to the expiry of their temporary operating licenses. Repowering, on the other hand, is not sensible or possible at all locations.[27] Added to this are rising raw material costs, which are making the resource-intensive expansion of wind power increasingly uneconomical. This is particularly true in the offshore sector.[28]

Therefore, replacement measures have already been initiated: Coal-fired power plants earmarked for decommissioning are being reactivated and put back into operation,[29] which actually contradicts the overarching goal of CO_2 reduction. Some coal-fired power plants have been transferred to the grid reserve in order to be additionally ramped up in the event of bottlenecks that are foreseeable in the longer term. However, these cannot be used in the case of short-term events or disruptions. Moreover, these costs are again "hidden" in the grid charges and passed on to all customers.

Whether it was forward-looking to shut down the German nuclear power plants before adequate replacements were available must be doubted. Despite the enormous expenditures for the energy turnaround, Germany remains one of the largest CO_2 emitters in Europe. In addition, German electricity imports have risen significantly. In late summer 2023, it is still argued that it is cheaper and more environmentally friendly to import electricity than to generate it in our own gas or coal-fired power plants. Whether this will also apply to the winter months remains to be seen, especially since many neighboring countries have already imported large amounts of electricity from Germany in the winter months.[30] Austria is leading the way.

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22 Cf. Macron will bis zu 14 neue Reaktoren bauen. https://www.zdf.de/nachrichten/politik/macron-atomkraftwerke-frankreich-100.html. Accessed on 23.10.2023.

23 Cf. https://de.statista.com/statistik/daten/studie/181801/umfrage/durchschnittsalter-von-atomreaktoren-in-ausgewaehlten-laendern-weltweit. Accessed on 23.10.2023.

24 Cf. Die Uhr tickt: Warum es dringend eine Gesetzgebung für Batteriespeicher braucht. https://www.pv-magazine.de/2023/09/11/die-uhr-tickt-warum-es-dringend-eine-gesetzgebung-fuer-batteriespeicher-braucht. Accessed on 23.10.2023.

25 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#kurzmeldungen. Accessed on 23.10.2023.

26 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#redispatch. Accessed on 23.10.2023.

27 Cf. https://www.tagesschau.de/wirtschaft/technologie/windkraft-abbau-windraeder-foerderung-ausgelaufen-eeg-101.html. Accessed on 23.10.2023.

28 Cf. UK Wind Auction Fails, Deepening Offshore Industry Troubles. https://www.bloomberg.com/news/articles/2023-09-08/uk-fails-to-clear-any-offshore-wind-in-renewable-energy-auction. Accessed on 23.10.2023.

29 Cf. Germany examines 1.9GW lignite winter 2023-24 return. https://www.argusmedia.com/en/news/2479617-germany-examines-19gw-lignite-winter-202324-return. Accessed on 23.10.2023.

30 Cf. Alle wollen importieren, nur niemand sagt, woher der Strom dann wirklich kommen soll … https://www.saurugg.net/2019/blog/stromversorgung/alle-wollen-importieren-nur-niemand-sagt-woher-der-strom-dann-wirklich-kommen-soll. Accessed on 23.10.2023.

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More and more countries want to import electricity from neighboring regions in the future and no longer produce it themselves. As long as sufficient generation capacities are still available in the neighboring regions, this is an economically sensible path. However, it puts a strain on the entire European grid and especially on the cross-border interconnectors. But also in the neighboring countries, with the switch to PV and wind power plants, there are more and more times when there is too much electricity available and other times when there is too little, mostly with very similar patterns. It is also a myth that the wind is always blowing somewhere.[31] This problem will become much worse with the increase in extreme weather conditions [see ACPP (2014)].

1.4.2 Insufficient grid infrastructures

Considerable challenges are also arising in the area of line infrastructure, as the wholly new generation structure is changing the demands on the grids in previously unknown dimensions. Traditionally, generation and consumption were spatially close together and connected by a hierarchically structured grid designed as a one-way street. Today, wind farms are mainly located far away from the centers of consumption. This makes large-scale expansion measures necessary at the transmission grid level. The situation is different for a large part of the existing PV plants. These are located at the local level. However, they feed into the lower grid levels in "reverse traffic" and increasingly lead to overloads at the distribution grid level,[32] which is not designed for such a development.[33]

The situation is further complicated by the fact that a large part of the distribution networks in Central Europe have been laid underground in recent decades to reduce weather-related outages. Retrofitting and upgrading therefore requires a great deal of effort, with a simultaneous lack of personnel and resources (see section on lack of resources).

Furthermore, the expansion of overhead lines is a massive problem in almost all countries because it often meets with great resistance from the population (NIMBY phenomenon - not in my backyard).[34] For example, the original plan was to complete the German north-south connections, which are to transport wind power from northern Germany - as far as available - to the consumption zones in southern Germany, by the end of 2022, when nuclear power is phased out. From today's perspective, the completion of the first main line ("Suedlink"[35]) can be expected from 2028 at the earliest. The German nuclear phase-out was completed on 15 April 2023. So far, it has gone smoothly and without any impact on supply. Whether this will also be the case in the future remains to be seen.

1.4.3 Aging infrastructures

The fact that many infrastructures are reaching the end of their life and use poses a further problem. ("Aging Infrastructures"). Many power plants and infrastructures are now 40 to 50 years old, some even significantly older. This means that extensive renewals would have to be carried out in the coming years in order to maintain the existing stock. However, this is often not economically feasible under the current economic considerations and uncertain framework conditions. Investments have therefore been postponed for years, which is likely to increase the susceptibility to failure. If investments are only made when it pays off or when consequential damage is already evident, it is too late. At the same time, many reserves that were still available have been used up in recent years in favor of optimizing business management. By the way, this is not only true in the energy industry, but in general.

In Germany alone, there are said to be more than 1,150 large transformers, of which an estimated 500 are already more than 60 years old. Due to increasing operating loads and irreversible aging processes, these will foreseeably reach the end of their useful life. They will therefore have to be replaced in the medium term.

However, the German production capacity for such plants is currently 2 to 4 units per year. In addition, many additional and new plants will be required as a result of the system conversion and the necessary digitization. Rapid upscaling of gener-

31 Cf. Le mythe du foisonnement éolien en Europe. https://participons.debatpublic.fr/uploads/decidim/attachment/file/425/Contribution2-MichelGay.pdf. Accessed on 23.10.2023.

32 Cf. Netzampel Übersicht. https://www.netzampel.energy/home. Accessed on 23.10.2023.

33 Cf. Photovoltaik: Mindestens 200 Betreiber speisen mehr Strom ein als erlaubt. https://www.nachrichten.at/wirtschaft/photovoltaik-mindestens-200-betreiber-speisen-mehr-strom-ein-als-erlaubt;art15,3880099. Accessed on 23.10.2023.

34 Cf. https://www.sn.at/salzburg/chronik/380-kv-urteil-entfacht-neuen-widerstand-67580512. Accessed on 23.10.2023.

35 https://suedlink.com. Accessed on 23.10.2023.

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ation capacities is additionally hampered by the limited availability of resources and skilled workers (see also the section on resources demand below).

1.4.4 Little-noticed resonance effects

A phenomenon that has received little attention so far are possible resonance effects and grid interactions between inverters and electronic components, which increasingly lead to disturbances, grid and system operation that have hardly been known so far and, in extreme cases, can even result in the destruction of equipment. These effects are hardly recognized with the methods and individual component considerations used so far.[36]

If previous observations confirm that this also causes electronic components and the insulation of cables to age more rapidly, this could also lead to significant disruptions in the infrastructure sector in the foreseeable future. Experts point out that the inverters installed today should be replaced by a new generation as soon as possible in order to limit possible damage.[37]

Another phenomenon is defensive decision-making [cf. Dueck (2015)]. Decision-makers tend to prefer not to tackle things that are not common practice in order to avoid the personal risk of possible failure. In this context, even a supposedly low risk for the decision maker himself influences his perception. That's why they often don't want to know exactly what's going on in their systems. Because if they did know, they would have to act, which usually involves investments. As long as everyone else does it that way, they can always talk themselves out of it by saying that everyone else has done it that way. Regulatory intervention will probably be required here to change this attitude.

Short-term, one-sided business optimization therefore blinds us to future developments and opens the way to strategic surprises. History is full of such examples of "creative destruction".[38] Nokia or Kodak are likely the best-known examples of this. What may still be acceptable in the economy in general is by no means acceptable for our vital power supply infrastructure. Failure would have devastating consequences for society as a whole.

1.4.5 Increasing compensatory measures

All these factors and other aspects lead to a rapid increase in costs and expenses for balancing measures. Power generation from renewable energies is naturally subject to constant and significant fluctuations and forecast deviations. Even though the weather forecast models are getting better and better, significant deviations occur again and again, which then have to be compensated for at short notice by other power plants within the framework of so-called redispatch measures.[39] These replacement measures are generally cost-intensive and are charged to the public via the network fees.

The costs of maintaining system stability in the European interconnected system have been rising for years. The Austrian congestion management costs, i.e. the expenditure for maintaining grid stability and thus for the acute avoidance of a blackout, have risen almost exponentially from 1.1 million euros in 2012 to 736 million euros in 2022. Instead of two interventions, over 300 interventions per year were necessary within a few years. Although this expense dropped significantly due to the electricity market separation between Germany and Austria in October 2018, 2019 and 2020, it has really exploded again since 2021, partly due to higher electricity prices.[40]

Germany has also seen a significant increase in procedures from 3,427 procedures in 2014 to 12,392 procedures in 2022 and 9,780 procedures by August 2023.[41]

The frequency of actually 50 Hertz in the European interconnected grid must be kept within the permitted range between 50.2 Hz and 49.8 Hz at all costs. Generation and load must always be balanced. From an overfrequency of 51.5 Hz,

36 Cf. https://www.saurugg.net/2020/blog/stromversorgung/versorgungssicherheit-strom-bedenkliche-ereignisse-2020. Accessed on 23.10.2023.

37 Cf. http://www.fette-competence-in-energy.com. Accessed on 23.10.2023.
Cf. https://cdnmedia.eurofins.com/european-west/media/1663280/swissengineering_de.pdf. Accessed on 23.10.2023.
Cf. https://publica.fraunhofer.de/bitstreams/bb9783ec-d4c1-460f-98e0-b3f2bd475fd0/download. Accessed on 23.10.2023.

38 Creative destruction (also creative destruction) is a term from macroeconomics whose core statement is: Every economic development builds on the process of creative destruction. Through a new combination of production factors that successfully prevails, old structures are displaced and ultimately destroyed. Destruction is therefore necessary - and not a system error - so that reorganization can take place. https://de.wikipedia.org/wiki/Sch%C3%B6pferische_Zerst%C3%B6rung. Accessed on 23.10.2023.

39 Cf. https://www.apg.at/de/Energiezukunft/Redispatch. Accessed on 23.10.2023.

40 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#epm. Accessed on 23.10.2023.

41 Cf. https://www.saurugg.net/blackout/risiko-eines-blackouts/aktuelle-situation/#redispatch. Accessed on 23.10.2023.

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plants are completely disconnected from the grid. From a frequency of 47.5 Hz, all power plants are disconnected from the grid and the power supply must be rebuilt afterwards. The reasons for increasing fluctuations, which have to be compensated for cost-intensively, are mainly the lack of adaptation of the system to the strongly changed framework conditions, e.g. due to the insufficient adaptation of a line infrastructure that has grown over a long period of time and the lack of storage facilities. During operation, countless new generators have to be integrated, and new consumers connected and supplied.

1.4.6 Lack of storage and buffers

Another central building block of the future electricity infrastructure and part of today's problems are storage and buffer systems (e.g. electrolyzers on the coasts), in order to process surpluses on the one hand, and on the other hand to be able to balance the volatile generation from renewable energies at any time and thus replace conventional power plants. This is not only about the described instantaneous reserve, but about a very wide time range: from inherent over seconds, minutes, hours, days, weeks up to seasonal storage.[42] This breadth of necessary storage and technologies is constantly discussed, especially by politicians, but is far from being implemented beyond pilot projects.

In Europe, there are always time windows of up to two weeks in which hardly any wind blows, nor does the sun shine ("Dunkelflaute"). Such periods must also be managed in a decarbonized system, even if they occur only very rarely. However, this would require an almost complete shadow infrastructure, as there have been no appropriate solutions for this so far, nor will there be in the foreseeable future [see Palmer et al. (2020)].

Alternatively, planned, spatially limited power cuts through power shortage management (so-called brownout) would also be conceivable - given a corresponding social consensus. [see Paulitz (2020)]. However, these would probably cause considerable damage, at least until this procedure has become established. Therefore, this is a path that hardly anyone is seriously considering at present. But burying one's head in the sand has never worked either.

However, there are always individual days when hardly any electricity can be generated from PV and wind power plants. Until now, these gaps could be covered by the still available conventional power plants. But with their successive dismantling, the available reserve capacities are becoming smaller and smaller.

While Austria has at least theoretically about 3,300 GWh and Switzerland about 8,900 GWh of (pumped) storage capacity, Germany as a whole has only about 40 GWh, even though 300 GWh of the Austrian capacity belongs to German companies. In Germany, there are no significant expansion plans or opportunities. Moreover, potential projects often fail due to resistance from citizens.[43] A large-scale storage facility is currently being planned in Austria, which will be connected directly to the German power grid. Planned completion: 2037[44]

With today's storage capacities, Germany could not even cover one hour of its own electricity consumption (between 60 and 80 GW). In addition, only around 11 GW of bottleneck capacity is available from (pumped) storage power plants, i.e. it can be called up at the same time. Across Europe, around 103 GW of pure storage capacity is available, of which 47 GW is pumped storage capacity.[45]

Electric vehicle batteries or home storage systems are therefore often mentioned as complementary solutions. These can certainly make a contribution. However, the orders of magnitude to be considered are often completely misjudged. If the wind blows optimally today in the Austrian province of Burgenland, where 445 wind turbines can generate a theoretical peak output of around 1.3 GW, around 18 GWh of surplus electricity is produced in one day. In Burgenland, which has a population of around 300,000 and no major consumers worth mentioning, this surplus electricity cannot be consumed by the region itself and must therefore be used elsewhere, temporarily stored or, in the worst case, regulated.

If this amount of energy were to be temporarily stored in average e-vehicle batteries (75 kWh), around 240,000 vehicles would be needed, which would have to be completely recharged from their fully discharged state in one day. If the wind stops blowing the next day, which is always the case, around 80,000 e-vehicles would be needed to supply Burgenland alone, which would then have to be fully discharged again. If one wanted to use home storage for this, one would need about 7.5

42 Cf. https://www.saurugg.net/energiezellensystem/die-zeit-in-der-elektrischen-energieversorgung. Accessed on 23.10.2023.

43 Cf. https://www.suedkurier.de/region/hochrhein/herrischried/einen-gedenkstein-fuer-das-pumpspeicherwerk-atdorf-hat-die-bi-atdorf-gesetzt;art372599,10939259. Accessed on 23.10.2023.

44 Cf. Leuchttürme der Energiewende: Österreichs stärkster Pumpspeicher. https://oesterreichsenergie.at/aktuelles/neuigkeiten/detailseite/leuchttuerme-der-energiewende-oesterreichs-staerkster-pumpspeicher. Accessed on 23.10.2023.

45 Cf. https://www.tugraz.at/fileadmin/user_upload/Events/Eninnov2016/files/kf/Session_A1/KF_Benigni.pdf. Accessed on 23.10.2023.

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times the amount, with the currently used capacity of about 10 kWh. This is purely mathematical because in reality, such storage units cannot be fully discharged, nor would the technical infrastructure be able to cope. And neither would the owners of the storage facilities.

In the energy transition so far, it has been neglected that conventional power plants on the one hand have integrated the storage in the primary energy (nuclear fuel rods, gas, coal, oil), and on the other hand support the frequency maintenance by balancing the existing flywheel masses. In the future, we will have increasing consumption, which will become more and more difficult to forecast, and at the same time increasing volatile power generation. Both cannot be reconciled without appropriate system adjustments.

1.4.7 Power-to-X

For seasonal storage, "Power-to-X" is now seen as a great hope, especially the use of hydrogen (H2). This also sounds very tempting, since the existing gas infrastructure would supposedly already provide an infrastructure that could be used for this purpose. However, the fact that there are still considerable hurdles to overcome is often concealed. This begins with the necessary infrastructure adaptation measures (tightness of pipes), the construction of correspondingly efficient electrolyzers, and ends with the lack of surplus energy, which is absolutely necessary and constantly available, in order to be able to produce hydrogen at all at reasonable costs and in reasonable quantities. Also, the import ideas are at present more hope than solutions in graspable proximity.

In addition, three times the volume of the comparable amount of natural gas is required for storage and transport.[46] At the same time, storage and subsequent conversion to electricity involve high conversion losses, requiring at least 3 to 4 times the energy for the same output. In the future, hydrogen will also be required on a large scale in many industrial processes in order to be able to reduce CO_2 emissions. This will result in a considerable competitive situation, which will probably have a further impact on availability and price.

The cost-benefit ratio is even less favorable for the production of e-fuels (power to liquid, power to fuel, PtF, P2F), which has been hailed as the "gold edge solution" for individual transportation [see Erlhofer (2023). p. 417ff]. E-fuels have poor efficiency. Batteries of 1,000 vehicles can be charged with the same amount of electricity. Due to the energy losses in the conversion of electric power, only 375 hydrogen-powered cars could run. With synthetic fuel, there would be only 156.

The prospect of a major production wave has triggered a gold rush, with promising announcements abounding. It is to be expected that one or the other "gold nugget" will also be found. However, it is not to be expected that this will lead to a major breakthrough and widespread implementation in the short term. Quickly implementable solutions are needed in the near future, however, and not in 10 or 20 years.

Second, there is little discussion of possible "side effects," such as the release of climate-impacting water vapor during large-scale reconversion. The same applies to the side effects of the planned methanation. Here, the effects are already known: Methane is significantly more harmful to the climate than CO_2. This issue also affects biogas plants.

1.4.8 Orders of magnitude

Many everyday discussions also show that very few people, and often many experts as well, have no idea of the magnitude of our energy consumption. A simple calculation example should make this clear.

One million seconds (comparable to one megawatt hour (MWh)) is about 12 days. One billion seconds (~ GWh) is already almost 32 years. For electricity storage, however, we are talking about TWh, or about 32,000 days.

What may work well on the small scale of a startup company, pilot or research project, says nothing about how fast and whether scaling is possible at all. On the other hand, financial viability and profitability must also be right, which is hardly the case today. When it comes to compensating for a very high-quality energy source in the form of fossil fuels, which has also been available at relatively low prices up to now, one quickly comes up against limits that are hardly surmountable, even if the sun and the wind do not send a bill, which is only a small part of the truth.

Therefore, apples are often compared with oranges, or average values are used which are hardly relevant for system security. For example, 143 gigawatts (GW) of installed wind power and PV capacity in Germany with a simultaneous consump-

46 Cf. Erneuerbarer Wasserstoff in Österreich. https://www.joanneum.at/fileadmin/user_upload/H2_Broschuere_final_2009.pdf. Accessed on 23.10.2023.

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tion of 60 to 80 GW sounds like a lot. But if you know that so far only on a few days a year an actual output of more than 60 GW could be generated, the situation looks quite different. It gets even bleaker if you take out individual outliers as on November 16, 2021. On this day, a minimum of just 0.23 GW was produced by wind power and PV plants. Calculated over the entire day, just 0.05 TWh was generated by wind and solar, out of a consumption of 1.46 terawatt hours (TWh). If biogas and hydropower are added, the combined total was 0.24 TWh.

On September 10, 2023, 68 GW of installed wind capacity generated a minimum of 0.1 GW, or 143 GW of PV and wind combined to generate 0.5 GW. For such days alone - even if they occur only rarely - almost one hundred percent of the shadow infrastructure would have to be kept available or large-scale shutdowns would have to be carried out to prevent a system collapse.

Comparing the cost of a kilowatt-hour (kWh) from nuclear, gas, coal, PV or wind power plants is also generally lame. One must not only compare the pure production costs. Most electricity sources also cause follow-up costs. This can be a simple dismantling of a wind turbine, but also complex costs such as the final storage of nuclear waste. Some of these follow-up costs can only be estimated. The respective subsidies must also be included in a comparison. Often the essential factor of a reliable supply over a defined number of hours per year is ignored. Therefore, there are hardly any usable and serious comparison values, even if this is often presented differently. For this, a full-cost calculation with the necessary storage costs and the additional infrastructure requirements would have to be made in order to establish comparability. In addition, the environmental costs caused by fossil power plants, for example, or other ancillary and consequential costs are part of an honest comparative calculation.

1.4.9 False claims of decentralization

People like to talk about decentralization taking place with the expansion of wind power and PV plants, which is a mistake. Because of the way the energy transition has been set up so far, more and more central structures are required, and the dependencies are not reduced, but even increased.

For example, although many PV systems are located at the low-voltage level, i.e. decentralized, the entire power supply would not function if the local excess power could not be transported away, which is now happening up to the extra-high voltage levels. On the other hand, it would quickly become dark when the sun goes down or clouds pass overhead and there would be no supply from the central system. Wind farms, too, can only be operated with the centralized system and the necessary balancing measures. We are currently a long way from true decentralization - which is what we should be aiming for.

One problem that still needs to be overcome is the replacement of the current instantaneous reserve.[47] Until now, it has been inherently available to the power system, due to the inertia of the rotating masses of conventional power plants. With the declining market share of conventional power plants, their system-supporting properties are only available to a significantly reduced extent at certain hours. In addition, large-scale power plants have so far been located predominantly in the south of Germany, while the mass of renewable energies are generated in the windy north or even offshore. Irrespective of the provision of system services such as the instantaneous reserve for security of supply, each TSO must also be guaranteed sufficiently dimensioned, secured generation capacity in the future to cover electricity demand in the event of a weather-related lack of generation from renewable energies. To this end, synthetic flywheel mass from wind energy conversion plants is also being discussed.

In addition, no one can currently really imagine how a power grid is to be restarted after a major disturbance with uncontrollable generation plants and a lack of control energy [cf. Reichl et al. (2015)]. Possible solutions are available. However, implementation is again lacking.

1.4.10 Decentralized functional units ("energy cells")

To speak of real decentralization, there would have to be the establishment of decentralized functional units ("energy cells").[48]

47 Cf. https://www.dena.de/fileadmin/dena/Dokumente/Pdf/9142_Studie_Momentanreserve_2030.pdf. Accessed on 23.10.2023.

48 Cf. https://www.saurugg.net/energiezellensystem. Accessed on 23.10.2023.

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More and more new installations are being added to the distribution networks: millions of small power plants, e-charging stations, heat pumps or air-conditioning systems as large consumers for which the infrastructure was never designed. In addition, numerous new players who want to anticipate the electricity market or contribute to the flexibilization of consumption have to be integrated and networked, which further increases the complexity of the system.

The particular problem here is that an increasingly complex system cannot be controlled with the central structure and logic that has been successful to date. Instead, this multitude of components and actors needs to be "orchestrated" so that they contribute automatically to ensuring security of supply.[49]

A cellular approach is therefore much more promising, since the increasing complexity will not be manageable otherwise.[50] Complex systems cannot be controlled centrally, but require decentralized autonomous units in which demand, storage and generation are balanced as locally or regionally as possible [cf. Vester (2011[8])].

Cross-system synergies are also to be exploited in the energy cell system. Sector coupling is to contribute to this: The electricity, heat and transport sectors must be restructured in such a way that they make better use of volatile renewable forms of energy in particular [cf. Erlhofer (2023). p. 281ff]. It is therefore a matter of a holistic energy supply in cellular structures, which require a comprehensive rethinking.[51]

Such an approach does not conflict with the existing large-scale system, which will still be needed to supply large industrial plants or cities. However, with these decentralized structures and functional units, the robustness of the overall system can be increased from the bottom up and in continuous operation without interruptions.[52] The basic idea and the basic infrastructure of the Internet are also based on these considerations.

Cellular structures may not be as efficient in ongoing operation as the previous large-scale system. This changes radically if there is a major disruption in the form of a blackout. Then, in one fell swoop, all previous efficiency gains would be wiped out, and enormous societal damage could be expected in an unforeseeable manner. Resilience and robustness are at odds with our purely business-motivated efficiency thinking, which is happy to dispense with redundancies and reserves that are essential for survival.[53]

A centralized approach, as currently often pushed with "smart grid" considerations, increases the central vulnerability of the system and should therefore be avoided. The idea of cell structure can also be derived from evolution, where all living things are organized in cell structures. This has obviously proven itself and survived. Everything else has been eliminated.

1.4.11 Reduction of energy demand versus increase in electricity consumption

To advance the energy turnaround and at the same time not overburden existing structures, a fundamental reduction in energy demand is essential. Everything that does not have to be required, generated and stored contributes most quickly to achieving the goal. There is also often still great potential here before the often feared loss of comfort occurs. The energy crisis of 2022, for example, brought this to light, when it suddenly became possible to make greater savings than had previously been assumed.

The desired decarbonization of all sectors (mobility, heating, industry, etc.) also makes it necessary to increasingly replace fossil fuels with electricity. At the same time, digitization, e-mobility, heat pumps and air conditioning will lead to a foreseeable further enormous increase in electricity demand. In addition, these applications have very high peak loads for which the existing infra-structures, especially the distribution grids, are not designed. Massive reinforcements and adaptations are therefore required. However, this will only be possible to a limited extent in the foreseeable future, so that considerable problems are emerging at the distribution grid level when, for example, excessive feed-in power or loads will increasingly lead to grid overloads.[54]

A more conscious use of energy and thinking beyond system boundaries to make optimal use of synergy potentials have not yet been achieved. In nature, in addition to the reduction of energy and resource requirements, decentralization as well

49 Cf. https://www.saurugg.net/2018/blog/stromversorgung/weckruf-orchestrieren-statt-steuern. Accessed on 23.10.2023.
50 Cf. https://www.saurugg.net/hintergrundthemen/vernetzung-komplexitaet. Accessed on 23.10.2023.
51 Cf. https://www.vde.com/de/presse/pressemitteilungen/vde-zeigt-loesungsansatz-fuer-zellulares-energiesystem. Accessed on 23.10.2023.
52 Cf. https://www.saurugg.net/2016/blog/energiezellensystem/spiders. Accessed on 23.10.2023.
53 Cf. https://www.saurugg.net/hintergrundthemen/resilienz-und-anpassung. Accessed on 23.10.2023.
54 Cf. https://www.netzampel.energy/home. Accessed on 23.10.2023.

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as fault-friendliness/tolerance and diversity have emerged as essential success concepts for (super-)viable complex systems. [cf. Vester (2011[8])]. However, these insights must first be incorporated into the ongoing transformation.

1.4.12 Digitization of the energy system

Digitization is one of the "magic words" that will influence all parts of society. The Internet of Things (IoT) will equip physical objects (washing machines, refrigerators and much more), networked objects (including cars, smartphones, fitness wristbands), conventional machines and digitized systems in factories, entire industrial processes and constantly more with information and communication technology (ICT; also information and communication technology), as well as sensor and drive technology (actuation technology) and also connect them to the Internet [cf. Erlhofer (2023). p. 410ff]. Electricity, the Internet and digitization can no longer be viewed in isolation from one another.

In the new electricity reality, consumers can no longer be guaranteed that they will be able to draw as much electricity as they would like at any given time because the electricity may not be available at that moment.

An "intelligent power grid" (smart grid, Internet of Energy) is intended to help with this scenario. It regulates the consumers in such a way that only as much power is drawn as is currently available: By means of the communication (data exchange) in both directions that a smart grid makes possible, the power draw can and will be favored in times of energy surplus or throttled when less energy is available [cf. Erlhofer (2023). p. 293ff].

The propagated "smart grids" and flexibility measures are also dependent on comprehensive central IT networking and thus on increasing complexity. In addition to the risk of cyber-attacks or incidents, this results in other side effects that have hardly been considered.

The smart grid will encompass all network levels and consumer groups. Innovative products (e.g., smart meters) and concepts (e.g. smart homes) promise an "intelligent" system, although the "intelligence" hides software-supported, complex communication systems. The central prerequisite is an exchange of information - in fact, an availability of data from the bottom up, in other words; a "transparent" customer who makes his data available without restriction.
Not only must everything be available, it must also be transparent, and secondly, it must be used consistently, i.e. across the board. Only then will the goals be attainable.

The customer is then told when he can defrost the refrigerator, wash the laundry, and dry it. It will no longer be a question of whether we minimize our own electricity bill through better technology (energy-saving light bulbs) or adapted behavior (switching off appliances that are in standby mode). We are supposed to re-learn and take action for the whole power grid. If we do not do this properly, we will be "punished" and asked to pay via higher tariffs.

With the increasing digitization of the power supply, the mutual dependencies are also increasing: without power, no IT. Without IT infrastructure, no power supply. Experts fear that even today, a possible network reconstruction could fail because more and more protective devices are being automated and there are fewer and fewer non-digital fallback levels.

Smart meters open up another field with "big data," which in turn can only be monitored and evaluated digitally.

In the "smart world", more and more digital applications are emerging in the electricity and flexibility market. What creates added value in everyday life can quickly turn into the opposite, as demonstrated by the serious cyber-attack on the largest oil pipeline in the USA in May 2021[55] or on the tank logistics company in Germany in February 2022[56] have shown. The war-related failure of 5,800 satellite modems in German wind turbines could also have triggered severe cascading effects.[57] Primarily regional providers are often not protected from hackers. So far, we have probably got off lightly more often than not, but this also contributes to a turkey illusion (see the section on turkey illusion below).

Four fields of risk all affect the sensitive "power system": force majeure, technology, organization and people. Because of the diversity of interfaces, it can only ever be relatively protected. The vulnerability remains and grows increasingly. The stressors always act in combination. Also there does not always have to be an intent to harm. Even an uncontrolled cyberattack - as in the case of the destruction of the satellite modems - or even a serious disruption can trigger cascading conse-

55 Cf. https://www.handelsblatt.com/unternehmen/industrie/colonial-pipeline-cyberangriff-legt-betrieb-grosser-benzin-pipeline-in-den-usa-lahm-/27173390.html. Accessed on 23.10.2023.

56 Cf. https://www.handelsblatt.com/unternehmen/energieversorgung-cyberangriff-legt-oiltanking-tanklager-deutschlandweit-vollstaendig-lahm-tankwagen-beladung-ausser-betrieb/28023918.html. Accessed on 23.10.2023.

57 Cf. https://www.reversemode.com/2022/03/satcom-terminals-under-attack-in-europe.html. Accessed on 23.10.2023.

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quences in the physical world, especially in a system as sensitive as the power supply. See, for example, the 2013 control system disruption in Austria.[58]

Here, too, an energy cell system would provide a remedy, since smaller units and structures are easier to control and rebuild, or errors or failures are easier to tolerate and cannot trigger large-scale effects. While some IT support is also required in the cells, the requirements are different from in a centralized system. This can significantly reduce the need for communication and content with other cells, and thus the attack surface. Fault tolerance at the decentralized level increases robustness at the central level and is an essential feature of viable systems.[59]

1.4.13 Resource demand

Although the primary energies of sun and wind are free, they are not available at all times, as our current power supply system requires, and the enormous resources and infrastructure required are not free either.

For example, to generate the same amount of energy as a coal-fired power plant, PV plants require twice as many resources, onshore wind plants five times as many, and offshore wind plants even seven times as many.[60] This does not even consider the additional infrastructure requirements due to a much higher demand for lines or storage.

Digitization and digital transformation, Industry 4.0, cloud computing, big data and analytics, smart homes and smart, autonomous machines, the Internet of Things and the Internet of Values (blockchain2, bitcoin), computing power, all require energy. Unprecedented amounts of raw materials are needed for its generation, storage and distribution. In addition, the transformation efforts in many world regions must be considered, which are accompanied by an even greater demand for resources. At the same time, only a few new deposits have been developed in recent years. Experience shows that it takes around 15 years to develop a new mine, so considerable bottlenecks and therefore enormous price increases are to be expected in the coming years,[61] which would further slow the transformation.

The U.S. Department of Energy analyzes in regular studie,[62] how the supply of critical raw materials for the energy transition is faring. The latest edition, dated May 2023, examines the availability of 23 materials critical to clean energy technologies. For 13 of these raw materials, the ministry sees significant risks that supply will not keep pace with demand: They include nickel, platinum, magnesium, silicon carbide and praseodymium, primarily because of their role in batteries and lightweight vehicle construction. But also neodymium, dysprosium and terbium, which are used in magnets in electric car motors and wind turbine generators, and natural graphite, which is becoming increasingly important for batteries. Rising demand for solar energy technologies, global electrification and lightweight vehicle construction will also make aluminum, copper, and silicon scarce in the medium term. Here, the analysts only consider the theoretical availability of the raw materials and not the actual availability resulting from the position of the individual countries in terms of extraction and processing.[63]

In all of this, there is a very high dependence on China. In addition to many important raw materials, a large part of the energy-intensive processing of raw materials into materials for further processing takes place in China [cf. Fremerey et al. (2022)].

When it comes to the topic of resource requirements, the shortage of skilled workers should also be mentioned, which does not stop at the field of electrical engineering. This is not only a matter of having enough assemblers for the installation of PV systems, but also for the entire infrastructure expansion and operation.[64] Nor should the focus be limited to electrical engineering alone. Because with the energy transition, more and more IT systems ("smart", flexibilization, etc.) are also needed. But there has been a glaring shortage of skilled workers, in particular, in the IT sector for a long time. And it is an international problem that affects many countries in Europe. As a result, the available personnel capacity is also becoming a limiting factor for the energy transition and secure system operation.

58 Cf. https://www.saurugg.net/blackout/risiko-eines-strom-blackouts/leittechnikstoerung. Accessed on 23.10.2023.

59 Cf. https://www.saurugg.net/hintergrundthemen/vernetzung-komplexitaet/#systemdesign. Accessed on 23.10.2023.

60 Cf. The energy transition delusion: inescapable mineral realities. https://www.youtube.com/watch?v=sgOEGKDVvsg. Accessed on 23.10.2023.

61 Cf. Critical Materials Assessment. https://www.energy.gov/sites/default/files/2023-05/2023-critical-materials-assessment.pdf. Accessed on 23.10.2023.

62 Cf. Mark Mills: The energy transition delusion: inescapable mineral realities. https://youtu.be/sgOEGKDVvsg. Accessed on 23.10.2023.

63 Cf. Rohstoffmangel wird Kernenergie zur Renaissance verhelfen. https://think-beyondtheobvious.com/stelter-in-den-medien/rohstoffmangel-wird-kernenergie-zur-renaissance-verhelfen. Accessed on 23.10.2023.

64 Cf. Elektrotechnik-Branche: Studie bestätigt akuten Fachkräftemangel. https://www.ove.at/ove-news/details/elektrotechnik-branche-studie-bestaetigt-akuten-fachkraeftemangel. Accessed on 23.10.2023.

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1.5 Further problem areas

In addition, there are further external factors that can endanger the security of the system. Of course, this list is not exhaustive.

1.5.1 Extreme weather events

As the climate crisis progresses, an increase in extreme weather events is also to be expected in Europe, such as those already observed in Australia, California, Texas, or in 2023 in many regions of Europe [cf. APCC (2014)]. Such events are often accompanied by severe infrastructure damage and failures.

Extreme drought causes cooling problems for conventional power plants. At the same time, the output of hydropower plants decreases due to falling water levels, or it is no longer possible to transport sufficient coal on the rivers to the power plants.[65] In the other extreme, flood or heavy rain events also cause problems with power generation, as in June 2020, when a heavy rain event shut down Poland's largest coal-fired power plant and led to a critical supply shortfall.[66]

Likewise, pumped storage power plants may reach their limits due to delayed snowmelt, as in spring 2021. Storm or freezing rain events can lead to widespread infrastructural failures, as in Münsterland in 2005.[67]

Energy cells would not be spared from such events. However, the risk of large-scale failures could be significantly reduced. Cells do not per se offer greater security of supply or robustness. But they do help to limit the potential for damage, which is becoming increasingly important considering the problems described.

1.5.2 Sabotage, terror, cyber-attacks

Furthermore, there are a number of other potential disruptive events that could lead to widespread power outages and are associated with an external intent to harm. The most severe sabotage attacks on critical infrastructure to date occurred in 2022 and 2023.

The destruction of the Nord Stream 1 and 2 gas infrastructure in September 2022 is unprecedented in Europe's history during non-war periods. Similarly, the destruction of a major dam in the course of warfare in Ukraine was unprecedented. Not to mention the fighting around nuclear-technical facilities.

Many things that were considered impossible until recently have suddenly occurred after all. There are also repeated sabotage attacks on Deutsche Bahn or on the electricity infrastructure.[68] Cyber-attacks anyway.[69] Therefore, no one can rule out the possibility of intentional or unintentional chain reactions in the power and supply infrastructure as part of a further escalation, which must not be disregarded.

Knowledge of complex systems shows that it is not enough to rely on the improbable not occurring. The combination of different disruptive factors that cannot be definitively controlled can and will lead to disruptions that carry the risk of failure of the overall system: climate and weather events, technical defects, human behavior, financial aspects, are only examples of "triggers" for such developments [cf. Erlhofer (2023). p. 410ff].

1.6 Risk assessment

This comprehensive, albeit far from conclusive, systemic examination of the current upheavals in the European power supply system has highlighted a number of problem areas, the increasing frequency and intensity of which are likely to have a foreseeable negative impact on the hitherto very high level of supply security in Europe.

Even if the various players are doing their best to maintain system stability and security, it should be clear that the risk of a large-scale outage inevitably increases under such conditions. Single events can be handled very well on a day-to-day basis without further public awareness, including media coverage. However, if several events occur simultaneously, or if there is even an external intention to cause damage, a phase transition and a large-scale system failure can quickly occur. It is not the

65 Cf. Niedrigwasser gefährdet Kohlekraftwerke: der bange Blick auf den leeren Rhein. https://www.rnd.de/wirtschaft/trockenheit-in-deutschland-das-niedrigwasser-im-rhein-gefaehrdet-kohlekraftwerke-NSYQHFXV3BE4RM764XV2NWTG5M.html. Accessed on 23.10.2023.

66 Cf. http://www.fette-competence-in-energy.com. Accessed on 23.10.2023.

67 Cf. https://www.bbk.bund.de/SharedDocs/Kurzmeldungen/DE/2020/12/15-jahre-schneekatastrophe-muensterland.html. Accessed on 23.10.2023.

68 Cf. Stahlträger durchgesägt – großer Strommast in Grevenbroich umgeknickt. https://rp-online.de/nrw/staedte/grevenbroich/grevenbroich-strommast-umgeknickt-sabotage-nicht-ausgeschlossen_aid-86460965. Accessed on 23.10.2023.

69 Cf. US-Energieversorger entdeckt mutmaßlich russischen Computer-Virus. https://www.berliner-zeitung.de/hacker-us-energieversorger-entdeckt-mutmasslich-russischen-computer-virus-li.407499. Accessed on 23.10.2023.

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probability but the expected damage that should justify a general blackout precaution, which will be discussed in more detail in the second part of this paper.

Previous methods for risk assessment and probability of occurrence calculation are only suitable to a limited extent here, since this is a High-Impact Low Probability (HILP) event, for which a probability calculation is not applicable due to a lack of evidence. Statements such as "there is no immediate or acute danger of a blackout, it is very unlikely that a blackout will occur, etc." may be correct at the moment and with a look in the rearview mirror, but they fail to recognize the current upheavals and systemic interrelationships.

They even lead to a dangerous false sense of security. After all, why should other actors concern themselves with the issue of precautions when it is unlikely anyway and at the same time there are many acute challenges to be dealt with in everyday life? Downplaying the danger ignores the scope of such a possible event and is irresponsible and even negligent considering the severe dislocations to be expected.

HILP events require complementary approaches, such as those based on the concept of antifragility [cf. Taleb (2013)] or on the methods of risk ethics, which focus not on probability but on the potential extent of harm [cf. Mukerji et al. (2020)], in order to derive necessary action. However, such an approach has been lacking in many fields. This deficit in mindset has a direct impact on the urgent need for safety communication. If it is not allowed to be, then there is no need to talk about it.

For this reason, most precautionary measures focus on avoiding such an event or are limited to the effects in the power supply system, which, however, falls far short [cf. ITA et al. (2022)]. This is exacerbated by the fact that the responsibility for establishing and maintaining protection and precautionary measures is assigned to the experts and operators of critical infrastructures and is removed from their own agenda.

The European power supply system has so far coped well with many non-systemic interventions. Therefore, there is definitely a belief in many areas that this will simply continue in the future, but this could turn out to be a major and dangerous fallacy. This potential fallacy is known in risk science as the turkey illusion [cf. Taleb (2013[5])].

1.6.1 Turkey illusion

A turkey that is fed daily by its owner while living in its social community assumes, based on its daily positive experiences (feeding and care), that the owner means well with it. The turkey does not only rely on the fact that the basic needs are satisfied from the outside. It also takes fundamental protection from danger for granted. The turkey lacks the essential information that this comprehensive care only serves the purpose of its being eaten in the end. On the day before Thanksgiving, when turkeys are traditionally slaughtered, it gets a nasty surprise.

This metaphor describes the frequent handling of rare events that involve huge societal impacts, so-called High-Impact Low Probability (HILP) events, extreme events ("X events"), or strategic shocks [cf. Casti (2012), Casti et al. (2017), Thurner (2020)]. The absence of evidence is often confused with the absence of events [cf. Taleb (2013)].

That's why the whole blackout precaution is not about probability, but about whether we as a society could cope with such an event. The energy industry will do everything it can to restore the power supply as quickly as possible. However, a blackout is not just a supra-regional power failure but leads to a far-reaching collapse of almost all supply structures, and the real crisis only begins after the blackout.

1.6.2 Major disturbances as possible warning signals

On January 8, 2021, and July 24, 2021, two major disturbances occurred in the ENTSO-E/RG CE network, each of which split the central European network into two subnetworks.[70] Compared with the most severe grid disconnection to date on November 4 2006, these two events were very mild. In 2006, around 10 million households in Western Europe had to be disconnected from the power grid within 19 seconds to prevent a Europe-wide blackout.[71]

On January 8, 2021, "only" large corporate customers in France and Italy were affected to the extent of Vienna's electricity consumption. These had previously contractually agreed to such emergency shutdowns and were also compensated for them.

70 Cf. https://www.saurugg.net/2021/blog/stromversorgung/bedenkliche-ereignisse-2021. Accessed on 23.10.2023.

71 Cf. https://de.wikipedia.org/wiki/Stromausfall_in_Europa_im_November_2006. Accessed on 23.10.2023.

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In the second major fault and grid disconnection on July 24, 2021, around 2 million customers on the Iberian Peninsula had to be taken off the grid to prevent anything worse.

Thanks to the continuously improved precautionary and communication measures of the European transmission system operators since 2006, the disruptions were eliminated and excellently controlled after one hour in each case. Nevertheless, such resynchronization is not trivial and regularly leads to total outages in the simulation. In addition, there have been "only" three other major disruptions with grid disconnections in the history of the network so far: blackout in Italy in 2003, Europe-wide in 2006 and blackout in Turkey in 2015.[72]

No one can guarantee that the planned safety mechanisms will be sufficiently effective and in time for the next incident. In the worst case, a supra-regional power blackout could indeed occur, as expected by the Austrian Armed Forces [cf. BMLV (2019)] or the author within the next five years, i.e. in the short term.

In any case, the two large-scale events in 2021 can be understood as serious warnings and "weak signals" in the sense of "dealing with the unexpected". [cf. Weick et al. (2010²)].

1.7 Summary

Conflicts of interest arise in every transformation. It would therefore be all the more important to address these clearly and make them transparent in order to obtain the broadest possible agreement. However, this is happening far too little, which is increasingly leading to disappointment and a loss of trust.

Large infrastructure projects need long-term planning security. However, this cannot be guaranteed due to short-term changes in the political framework, such as the German coal phase-out. Until 2022, an ever faster phase-out was demanded and paid for with large sums of money.[73] In autumn 2023, however, it was decided to extend the operating lives of coal-fired power plants already scheduled for closure until at least March 2024.[74] An extension of the operating times beyond that is already being discussed.[75]

Each new intervention leads to delayed effects and to an ever-decreasing willingness to invest in long-term infrastructure projects. Especially when the decision is no longer factually comprehensible. In addition, the short-term, narrow view of business management prevents viable long-term solutions from being found. Instead, we are seeing more and more dangerous actionism, with people resorting to quick-and-dirty solutions. [cf. chapter “The Dark Side of Digitalization”].

These focus on the symptom and can often be implemented quickly, while a fundamental solution attempts to eliminate the cause of the problem. Quick-and-dirty solutions make the actual problem worse in the long term, while fundamental solutions often bring significant disadvantages in the short term and only prove beneficial in the long term [cf. Ossimitz (2006)]. This is a problem that runs through the entire energy transition.

Many actors also assume that the market will sort it out if only it is allowed to. This is also a very daring and dangerous approach in a system in which the availability of the necessary resources must be permanently guaranteed. After all, the pure market also provides for failure and elimination, which is tantamount to suicide in the power supply system.

In the worst case, the state, i.e. the public, has to step in to ensure security of supply. Provided this happens in time. The 2022 gas crisis can be taken as an example here. Although there were warnings of insufficient gas supplies as early as mid-2021, they were apparently ignored. When the situation escalated completely in mid-2022, gas was purchased at any price, which drove up prices even further. Fortunately, the winter of 2022/23 was very mild, which meant that expected escalations did not occur.[76] Only the future will show whether this will also be the case in the coming winter.[77] [78] However, it may be doubted whether it is wise to rely more and more on lucky circumstances.

72 Cf. Blackout in der Türkei: War eine Kette von Fehlern verantwortlich?. https://www.saurugg.net/2015/blog/stromversorgung/blackout-in-der-tuerkei-war-eine-kette-von-fehlern-verantwortlich. Accessed on 23.10.2023.

73 Cf. Wie die Bundesregierung Milliarden für den Kohleausstieg hochrechnete. https://correctiv.org/aktuelles/2021/05/15/bundesregierung-milliarden-fuer-kohleausstieg. Zugriff am 21.10.2023.

74 Cf. Bund reaktiviert Reserve von Kohlekraftwerken. https://www.tagesschau.de/wirtschaft/energie/braunkohle-reserve-winter-100.html. Accessed on 23.10.2023.

75 Cf. Laufen Deutschlands Kohlekraftwerke länger als geplant?. https://www.handelsblatt.com/unternehmen/energie/energieversorgung-laufen-deutschlands-kohlekraftwerke-laenger-als-geplant/29456270.html. Accessed on 23.10.2023.

76 Cf. Katastrophenwinter 2022/23 – Fiktion oder bald Wirklichkeit?. https://www.saurugg.net/wp-content/uploads/2022/07/gfkv-katastrophenwinter-2023.pdf. Accessed on 23.10.2023.

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One of the biggest hurdles in the necessary adaptation seems to be our linear "either-or" thinking framework. For dealing with complexity, however, a "both/and" way of thinking is imperative, which can also deal with the contradictions and conflicting goals, as these are unavoidable [cf. chapter “The Dark Side of Digitalization”] and [cf. Erlhofer (2023). chapter 4].

A functioning and affordable power and energy supply in general is an essential prerequisite for social prosperity, so that interventions in this area should be made very carefully and deliberately, which also requires an ongoing examination of possible side effects.

The "secondary risk" must not be lost sight of. This refers to incalculable societal "side effects" that manifest themselves in a loss of political trust, disenchantment with politics, angry citizens and a shift away from conventional political structures. These cannot be calmed with the well-rehearsed rituals of "classical risk assessment".

77 Cf. Deutschland prüft 1,9 GW Braunkohle Rückkehr für den Winter 2023-24. https://www.argusmedia.com/en/news/2479617-germany-examines-19gw-lignite-winter-202324-return. Accessed on 23.10.2023.

78 Cf. Ungewisse Stromlage für den kommenden Winter. https://www.srf.ch/news/schweiz/energieversorgung-ungewisse-stromlage-fuer-den-kommenden-winter. Accessed on 23.10.2023.

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2 A supraregional power blackout

A major supraregional disruption in the form of a blackout is the result of a massive power imbalance in the European interconnected system. In principle, there are extensive safety mechanisms to prevent such a serious event. However, there is no such thing as one hundred per cent certainty, as the European transmission system operators also made clear in 2015 after the blackout in Turkey:

> "A large electric power system is the most complex existing man-made machine. Although the common expectation of the public in the economically advanced countries is that the electric supply should never be interrupted, there is, unfortunately, no collapse-free power system." [ENTSO-E (2015). S. 46.]

The consequence of such a power imbalance would be a large-scale, fully automatic disconnection of customer installations and equipment within seconds to minutes. Parts of the transmission network or the entire distribution network would then lack voltage. These measures serve to protect the operating equipment from physical damage.

Depending on the size and cause of the outage, different "blackout concepts" are then required for network reconstruction. If the outage is not too widespread and sufficient voltage is available from neighboring grid regions, the grid can probably be reconstructed relatively quickly by simple reconnection measures.

If, for whatever reason, this is not possible, a black start is carried out with specially prepared and suitable black-start capable power plants, of which there are only a few. This is because most power plants cannot start up without external voltage.

In Austria, there are about 2 black start-capable power plants, in Switzerland 4. There are indeed a number of other small plants in Austria. However, the number alone says nothing about the speed of grid reconstruction. This is because more plants generally mean less output and more coordination effort.

Network reconstruction is regularly practiced on simulators. Whether everything works as planned in reality is not known in advance. In any case, smaller and larger surprises always occur during real-life exercises.

DUtrain operates its own independent training center in Duisburg, where training courses and seminars are offered on the topics of generation, transport and distribution of electrical energy and natural gas. The operating personnel of numerous national and international network and power plant control centers have prepared themselves here for expected critical events.

On April 30, 2022, the transmission system operators Amprion and TransnetBW together with Schluchseewerk AG practiced under real conditions. In contrast to previous virtual simulations, part of the real grid was disconnected, shut down and reconstructed. Amprion writes: "Severe disturbances are rare. The system is designed in such a way that even in the event of faults, there are no restrictions for end customers. Nevertheless, the transmission grid can theoretically reach its technical limits - in the worst case, there would be a European blackout. In this unlikely event, the entire transmission network would be de-energized and no electricity would flow. Before end customers can be supplied again, the transmission grid must be energized step by step."[79] This exercise was prepared over a period of four years. Detailed planning was developed and coordinated under the project management of Amprion. The Chair of Energy Systems and Energy Management at the Technical University of Kaiserslautern provided support, among other things, in setting up measuring equipment with which the grid could be measured in all areas during the conversion. "There has never been such a test setup in Germany before, and the measurement effort was the largest of its kind." The data obtained is now being evaluated and processed together with the Chair of Electrical Energy Systems at the University of Duisburg-Essen. None of this would be done and financed if there were not a concrete need. Many recovery concepts are based on assumptions from the old energy world that can hardly keep up with the increasing changes and complexity. This applies in particular to the massive power plant shutdowns in Germany, which can lead to uncontrollable system states even in the event of a grid separation ("system split") as on January 8 or July 24, 2021, if, for example, there is too little rotating mass in a sub-segment to be able to absorb the load jumps that occur during the outage or even during the restart [cf. momentary reserve in the section "Lack of storage and buffers" before]. On the other hand, reliably available and controllable power plants are absolutely necessary for network reconstruction.

There may be experts who consider such an event to be completely impossible. And so far, experts have found causes and explanations for all power failures experienced: after the respective incident. Some of the causes were known beforehand. However, something was not always done about it.

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79 Cf. Netzwiederaufbau in Süddeutschland - Hochfahrnetze im Praxistest. https://www.amprion.net/Netzjournal/Beiträge-2022/Hochfahrnetze-im-Praxistest.html. Accessed on 23.10.2023.

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In the German-speaking world, two incidents are remembered and influence the images in our minds: the widespread power outage in Münsterland on the first Advent weekend in 2005, caused by a weather event, and the power outage on Saturday, November 4, 2006, around 10:10 p.m., which made it dark in parts of Germany, France, Belgium, Italy, Austria, Spain, and even had an impact in Morocco.[80]

In the first case, it was primarily natural forces, in the second a chain reaction triggered by a human error that was subsequently determined to be the cause [cf. Ministry of the Interior of Baden-Württemberg (2010)].

Experts had already examined the issue of "extreme winter weather with widespread power outages" in November 2004 (!). This was the main subject of the first three-day interstate and interdepartmental crisis management exercise (LÜKEX). The exercise topic "power blackout" was chosen regarding the hurricane "Lothar", which had led to power blackouts lasting several days in Switzerland in 1999.

In the 2008 Green Book of the Future Forum on Public Safety (ZOES), different risks are described: in the third chapter the scenario "Power blackout in Germany" [cf. Reichenbach (2008)].

In 2008, the Office of Technology Assessment at the German Bundestag (TAB) was commissioned to systematically analyze the consequences of a large-scale and prolonged power blackout. The aim was to describe the possibilities and limits of the national disaster management system for coping with such a large-scale supraregional disaster [cf. Petermann et al. (2010)].

The final report presented in November 2010 describes how vulnerable information technology and telecommunication, transport and traffic, energy supply and health care are.

In 2019, the German Federal Office of Civil Protection and Disaster Assistance published the results of a research project entitled "Scenario-based fundamentals and innovative methods for reducing the risk of power supply failure, considering the impact on the population" (GRASB).[81] This project had investigated what can be done beyond existing measures by operators of critical energy infrastructure and authorities to reduce the risk of power supply failure. This brought the aspect of prevention for civil protection into focus. But again, this came almost exclusively at the technical level.

Further studies have examined power failure and the possible consequences in different contexts, for example: TankNotStrom (supply of operating materials for emergency power generators and "shining islands")[82], SIMKAS-3D (Cascading effects between different supply infrastructures.).[83]

So no one should say that a blackout is a completely unthinkable event. It's like the pandemic that could turn our lives upside down within a few days. It, too, was not unknown to experts until March 2020. Only for many decision-makers and the population, it seemed unimaginable. Thus, it joins events like the renewed conventional war in Europe or the destruction of a central infrastructure like Nord Stream 1 and 2. Therefore, a reminder of the turkey illusion should be made again at this point [cf. Erlhofer (2023). chapter 2].

2.1 Definition Blackout

Since there is no universally accepted definition for the term "blackout", it is important to provide one for the present consideration. In this sense, the author understands a blackout as:

> A sudden, supra-regional and prolonged power, infrastructure and supply failure affecting at least several states or larger areas of the country. Outside assistance is not expected. [84]

This definition contradicts the inflationary use of the term in many media for almost any power outage. This often makes a well-founded discussion difficult. In the energy industry, too, the focus is often limited to the duration of the power black-

80 Cf. Historische Stromausfälle. https://de.wikipedia.org/wiki/Liste_historischer_Stromausf%C3%A4lle. Accessed on 23.10.2023.

81 Cf. https://www.sifo.de/sifo/de/projekte/schutz-kritischer-infrastrukturen/schutz-vor-ausfall-von-versorgungsinfrastrukturen/grasb/grasb-szenarienorientierte-gru-wirkungen-auf-die-bevoelkerung.html. Accessed on 23.10.2023.

82 Cf. https://www.sifo.de/sifo/de/projekte/schutz-kritischer-infrastrukturen/schutz-vor-ausfall-von-versorgungsinfrastrukturen/tanknotstrom/tanknotstrom-energie-und-kraft-romaggregaten-bei-stromausfall.html. Accessed on 23.10.2023.

83 Cf. https://www.sifo.de/sifo/de/projekte/schutz-kritischer-infrastrukturen/schutz-vor-ausfall-von-versorgungsinfrastrukturen/simkas-3d/simkas-3d_node.html. Accessed on 23.10.2023.

84 In Anlehnung an den wissenschaftlichen Bericht Energiezelle F. www.saurugg.net/ezf. Accessed on 23.10.2023.

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out, which is far too short-sighted and thus counterproductive for the necessary crisis prevention. See, for example, the definition of the Austrian transmission system operator Austrian Power Grid:[85]

> "A blackout is an unexpected, widespread, nationwide power outage - regardless of its duration."

Large-scale power failures occur time and again in various regions of the world. Europe has so far been largely spared such events, with the exception of blackouts in parts of Germany/Austria/Switzerland (1976), Italy (2003) or Turkey (2015).[86] All other major blackouts, such as the one in Münsterland (2005), in Slovenia (2014) or the large-scale load shedding in Western Europe (2006), were not real blackouts because there was no large-scale system collapse in which the frequency in the affected area would have fallen completely to zero.

The real danger, therefore, does not come from the blackout, but from the resulting and prolonged supply interruptions in all areas of life, which can bring our present (unprepared) society to the brink of collapse within a few days. This is also because, due to the magnitude of the event, help from outside the affected area can hardly be expected, as everyone is affected themselves and there will hardly be any free resources available.

Even a large-scale power blackout lasting just a few hours and extending over larger areas or several states would have the potential to trigger the most severe consequential damage in production and logistics, since neither the population nor the companies or the state are prepared for such events. This was already noted in 2010 in the study by the Office of Technology Assessment "Risk and vulnerability of modern societies - using the example of a large-scale and prolonged power supply failure":

> "Due to the almost complete penetration of the living and working environment with electrically operated devices, the consequences of a long-lasting and widespread power blackout would add up to a damage situation of special quality. All critical infrastructures would be affected, and a collapse of society as a whole could hardly be prevented. Despite this potential danger and catastrophe, societal risk awareness in this regard is only rudimentary." [Petermann et al. (2010). p. 4.]

> "The impact analyses have shown that after just a few days in the affected area, it is no longer possible to ensure the nationwide supply of (essential) goods and services to the population in line with their needs." [Petermann et al. (2010). S. 15.]

Social vulnerability has certainly increased further in the past 10 years. The level of preparedness has tended to fall during this time, as in many companies or even in the state itself, fallback levels, reserves and stocks have been readily saved as "dead capital" for business management reasons. This is what makes a possible blackout a real and underestimated threat to society.

2.1.1 Power shortage situation

What is considered more likely in expert circles is a power shortage. This means that a massive shortfall in coverage is already apparent in advance. Depending on the region and the problem, this can be announced at very short notice, hours or days in advance. In Switzerland, one tends to expect a longer lead time, but also a possible shortage situation over weeks.

If the demand cannot be reduced sufficiently, power shortage management in the form of preventive disconnections of consumers ("brownout") must be implemented to prevent an unplanned large-scale outage. In the best case, this will only affect large consumers who have contractually agreed to do so and receive compensation for this. If this is not sufficient, rolling area-wide shutdowns could also be necessary, such as in Kosovo in the winter of 2021/22.[87] or in Turkey [88].

In recent years, there have also been in Belgium [89] or France [90] corresponding preparations, but these have not yet had to be used. In Switzerland, too, many companies were warned of possible rationing in the winter of 2021/22.[91]

85 Cf. Austrian Power Grid: Sichere Stromversorgung, FAQ. https://www.apg.at/stromnetz/sichere-stromversorgung. Accessed on 23.10.2023.
86 Cf. Historische Stromausfälle. https://de.wikipedia.org/wiki/Liste_historischer_Stromausf%C3%A4lle. Accessed on 23.10.2023.
87 Cf. https://perspektive-online.net/2022/01/stromkrise-taeglich-stundenlange-stromausfaelle-im-kosovo. Accessed on 23.10.2023.
88 Cf. https://www.handelsblatt.com/politik/international/erdgasmangel-es-herrscht-panik-tuerkische-regierung-schaltet-der-industrie-im-land-den-strom-ab/28001710.html. Accessed on 23.10.2023.
89 Cf. https://www.saurugg.net/?s=belgien. Accessed on 23.10.2023.
90 Cf. https://www.saurugg.net/?s=frankreich. Accessed on 23.10.2023.
91 Cf. https://www.ostral.ch/de. Accessed on 23.10.2023.

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Few European companies and infrastructure operators would be prepared for such a situation today. As in the case of a blackout, considerable damage and disruptions would have to be expected in other areas of the infrastructure and thus in logistics as a whole. Here, too, the complex interdependencies and interactions are often underestimated, as was already warned during the Swiss safety association exercise in 2014:

> "It is not the power outage, but the prolonged power shortage that is emerging as the greatest challenge in the SVU 14 scenario. A total failure of certain critical infrastructures is very likely because less electricity often does not mean that fewer of such infrastructures work, but that nothing works at all. Information and communication technologies (ICT) control important systems (transportation, telephony, warehousing, payment transactions, etc.). Today, nothing works without ICT, but ICT does not work without electricity. In this situation, diesel or other fuels are indispensable as a substitute for local electricity production. Maintaining the basic supply of consumer goods for the population very quickly becomes central and very difficult to do. Moreover, since the usual communication channels are very limited, a prolonged power shortage situation should not be underestimated, but is a Herculean task for all involved."[92]

A prolonged power shortage could also be caused by a blackout, if operating resources are damaged and sufficient generation and/or transmission capacities are not available for a longer period of time. In Switzerland, such a scenario has been considered the most probable and at the same time the most serious risk for Switzerland since 2012.[93]

2.2 Consequences and duration of a blackout

A Europe-wide, transnational major disruption would immediately lead to a large-scale failure of most critical infrastructures (CRITIS) [cf. Pertermann et al. (2010), Reichl et al. (2015), Erlhofer (2023)]. This would start with telecommunications (mobile, fixed, Internet), which, along with electricity, would cause the two most important lifelines of our modern society to fail. As a result, virtually all utility services would fail or be available only to a very limited extent: the financial system (ATMs, cash registers, money and payment transactions), traffic (traffic lights, tunnels, trains, gas stations) and thus the entire supply logistics (food, medicines, goods of all kinds), all the way to regional or large-scale failures in water supply and wastewater disposal. Not to mention tens of thousands of people who would possibly be stuck in elevators, trains or, in winter, ski lifts. Residents of high-rise buildings who are not fully mobile would no longer be able to reach or leave their apartments. Everyday life would come to a standstill from one moment to the next.

A large-scale failure of the telecommunications infrastructure, for example as a result of a cyber-attack or a severe earthquake, could have similarly far-reaching consequences. An intensified pandemic in which significantly more people fall ill at the same time would also foreseeably lead to massive supply interruptions and bottlenecks. Our highly optimized and efficiency-boosting just-in-time logistics system hardly has any reserves or fallback levels to compensate for the expected widespread infrastructure or personnel shortages.

The fragility of logistics chains [cf. CSH (2020)] could be observed in several examples in 2021. In the event of a blackout, in which larger parts of Europe come to a standstill at the same time, the effects would be many times more serious. Therefore, a global shock effect and long recovery times are to be expected.

2.2.1 Phase 1 – total power and infrastructure failure

A blackout can be divided into three main phases:

In Austria, for example, a power outage lasting around 24 hours is expected.[94] Parts of the regional power supply can probably be restored much faster. In other parts, it may take longer. Metropolitan areas should be restored as a priority.
Austria has a great advantage over many other countries when it comes to restoring the grid, thanks to its two large pumped-storage power plants that can be black-started and regulated. This would make it possible to rebuild the grid much more quickly than in many other countries.

92 SVU'14 – Newsletter Juni. https://www.saurugg.net/2014/blog/newsletter/svu14-newsletter-juni. Accessed on 23.10.2023.

93 Cf. https://www.saurugg.net/?s=risikobericht+schweiz. Accessed on 23.10.2023.

94 Cf. „Blackout"-Gefahr: Stromausfall-Vorsorge in Österreich wird verstärkt. https://www.tt.com/artikel/30802053/blackout-gefahr-stromausfall-vorsorge-in-oesterreich-wird-verstaerkt. Accessed on 23.10.2023.

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At the European level, depending on the outage scenario, a restoration time of up to one week is expected until the power supply is stable again everywhere. However, a large-scale power outage over several weeks would have catastrophic consequences for the affected region, as the Office of Technology Assessment at the German Bundestag warned back in 2010:

> "By the end of the first week at the latest, a catastrophe would be expected, i.e. the health damage or death of very many people and a problem situation that could no longer be managed with locally or regionally available resources and personnel capacities." [Petermann (2010). S. 10.]

Estimates of whether it could last only hours, days or perhaps even weeks vary widely and are also associated with many uncertainties.

In any case, the actual duration depends largely on the triggering event and the size of the failed area. If sufficient voltage can be transferred from neighboring, non-failed network areas, restoration can also be significantly faster. If the infrastructure was damaged or even sabotaged during the outage, it can also take significantly longer. If there is not enough power plant capacity available after the restoration, power shortage management may also be necessary. So there are many factors of uncertainty.

Many other infrastructures should not be reconnected to the grid until the power supply is sufficiently stable and reliable. Otherwise, voltage, current and frequency fluctuations can lead to further damage to equipment and infrastructure. For this reason, it is advisable to wait as long as possible before restarting operations until it is clearly communicated that the European interconnected system is once again functioning in a sufficiently stable manner and that there is no threat of another immediate outage. This is also because experience from simulation-based network reconstruction training shows that total failures repeatedly occur when subnetworks are interconnected.

In the event of a power failure, emergency power generators are kept on hand in various critical areas. But here, too, it is apparent that the performance and reliability are often overestimated.,[95] which was demonstrated, for example, by the 31-hour power failure in Berlin-Köpenick in February 2019, where the emergency power generator of the DRK clinic failed after 7 hours of emergency power operation. 23 intensive care patients had to be evacuated.[96] This would not be possible in the event of a blackout.

In the White Paper Grid and Supply Reconstruction 2030, the German transmission system operators describe that:

> "According to a risk assessment of the TSOs (...) due to the changes in the generation portfolio, the decentralization of generation capacity and the elimination of large thermal power plants, the network reconstruction [will] become more small-scale and complex, which will have a negative impact on the expected duration of the network and supply reconstruction. For this reason, the minimum 24-hour blackout period required in Article 41 of the ER Regulation was increased to 72 hours in Germany. The TSOs are thus following a recommendation of the Federal Office of Civil Protection and Disaster Assistance (BBK) for operators of critical infrastructures.[97]

Nevertheless, they point out that:

> "...in all likelihood, it will not be possible to connect a predominant portion of the small-unit DEA over 72 h in a black-fall-proof manner."

The TSOs are therefore by no means certain that they will be able to completely restore the supply network within three days. They already describe 2020 in their "Considerations on network and supply reconstruction":

> "For the time period of the network reconstruction, this means that the TSOs will push ahead with the completion of the "Network reconstruction TSO" package of measures as quickly as possible, both today and in the future. However, it will have to be continuously reviewed whether the time span of 24 hours or, prospectively, 72 hours can also be adhered to in the future regarding the changing framework conditions."[98]

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95 Cf. Was so alles schief gehen kann und geht. https://www.saurugg.net/blackout/auswirkungen-eines-blackouts/was-so-alles-schief-gehen-kann-und-geht. Accessed on 23.10.2023.

96 Cf. https://www.deutschlandfunkkultur.de/ein-jahr-blackout-in-berlin-koepenick-passiert-halt-100.html. Accessed on 23.10.2023.

97 Weißbuch_NWA_VWA_2030. https://www.netztransparenz.de/Weitere-Veroeffentlichungen/Wei%C3%9Fbuch-Netz-und-Versorgungswiederaufbau-2030. Accessed on 23.10.2023.

98 Betrachtungen zum Netz- und Versorgungswiederaufbau, Teil des Berichts der Deutschen Übertragungsnetzbetreiber gem. § 34 (1) KVBG, Bayreuth, Berlin, Dortmund, Stuttgart 22.12.2020. https://www.netztransparenz.de/portals/1/20201222%204UeNB%20Bericht_%C2%A7%2034%20KVBG.pdf. Accessed on 23.10.2023.

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But not every emergency generator behaves as intended. A common problem is the fuel quality of emergency generators, as a German study from 2014 showed. At that time, about 60% of the fuel examined was defective or deficient. Only 6% were faultless.[99]

In general, it can be seen that an emergency power supply should also be tested regularly over a longer period of time in order to really be able to assume that it will function smoothly when needed.[100] There are too many potential sources of error.

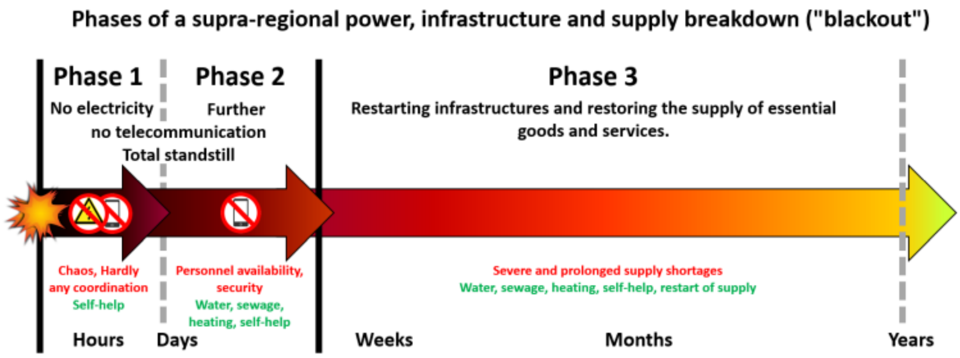

Fig. 1: Phases of a blackout

2.2.2 Phase 2

Up to now, many preparations have focused exclusively on this phase 1 of the power blackout, which falls far short. Phase 2 is completely underestimated, until the telecommunications supply with fixed network, mobile communications and Internet should be largely stable again after the power blackout. Expected severe hardware failures and malfunctions as well as massive overloads during the restart mean that a recovery time of at least several days is to be expected. The longer the power outage lasts, the more severe the damage is likely to be, especially in the backbone systems.

In regions where the power outage lasts longer than 48–72 hours, the recovery time for these core infrastructures is difficult to calculate because by then most of the emergency power systems will usually have failed. At that point, major damage to IT components can be expected.

The main problem is dried-out electrolytic capacitors. This is not noticeable during operation. However, if the power fails, this component will be destroyed when it is switched back on, causing the entire component to fail.

It is to be expected that this will lead to a spare parts problem, since a short-term external replacement will hardly be possible due to the lack of communication possibilities and the high simultaneity requirements.

Such failures and malfunctions can occur in any infrastructure, especially if it is basically never switched off, which also affects the entire building control system. If a regular complete shutdown were carried out, these defects would be noticed regularly and could be repaired in time. In many complex systems, however, shutdown is no longer possible. Therefore, the foreseeable problems accumulate here and then become effective at the same time.[101] A fatal development.

Without telecommunications, however, neither production nor logistics chains nor fuel logistics will function, and thus neither will the supply of vital goods and services to the population.

Health care (hospitals, general practitioners, pharmacies, nursing care, etc.) will also function only to a limited extent or not at all. Hospitals do have an emergency power supply. However, this can often only supply the most important areas. On

99 Cf. Neue Erkenntnisse zur Lagerfähigkeit von Brennstoffen für Netzersatzanlagen. https://www.saurugg.net/2015/blog/stromversorgung/neue-erkenntnisse-zur-lagerfaehigkeit-von-brennstoffen-fuer-netzersatzanlagen. Accessed on 23.10.2023.

100 Cf. Blackout-Vorsorge: Der Teufel steckt im Detail. https://www.saurugg.net/2020/blog/krisenvorsorge/blackout-vorsorge-der-teufel-steckt-im-detail. Accessed on 23.10.2023.

101 Cf. Stromausfall im MDR-Funkhaus in Halle. https://www.mdr.de/nachrichten/sachsen-anhalt/halle/halle/funkhaus-halle-stromausfall-100.html. Accessed on 23.10.2023.

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the other hand, there is a very high dependence on external supply and disposal services, with the result that medical care will quickly be very limited. The availability of personnel will have a particularly critical impact [cf. Petermann et al. (2010)].

At the same time, the study "Nutritional Precautions in Austria" [cf. Kleb et al. (2015)] and comparable studies from Germany come to the conclusion that by the fourth day of a blackout-related supply interruption at the latest, around one third of the population is no longer in a position to provide for itself adequately. After seven days, around two thirds, or about six million people in Austria could already be affected.

Tourists or commuters, who will be dependent on outside help in any case, have hardly been considered yet. There are no governmental or other provisions that could absorb such a major event. The helpers and their families are also directly affected by the consequences.

It is only this concatenation of all impacts that leads to a real disaster.

Although there have always been recommendations that the population should build up a personal emergency stockpile, this practice was discontinued in large parts of Central Europe at the latest after the end of the Cold War more than 30 years ago. That is the curse of the very high security of supply in all areas of life, whether electricity, water, food or health: there is always something there, and if there is a problem, someone is quickly on hand to help. This will not work in the event of a blackout.

That is why precautionary recommendations such as "Good Advice - Emergency Stockpile" in Switzerland[102], the recommendations of the German Federal Office of Civil Protection and Disaster Assistance (BBK)[103] or the Austrian Civil Protection Association [104] are more topical than ever. They rarely reach the general population.

The Society for Crisis Preparedness (GfKV)[105] is therefore attempting to make Austria fit for the crisis with the initiative "Join in! Austria becomes fit for the crisis![106] Or "Fit for the crisis step by step[107] to make this topic socially acceptable again and to bring it out of the niche corner.

One basic problem is certainly the inadequate communication of risks and safety to convey the need for precautions to the population. And not only when a crisis has already occurred, but long before. This is why overreactions occur quickly in actual crisis situations, such as the excessive purchase of toilet paper or potassium iodide tablets in March 2022 before the first lockdown in 2020. Society lacks a general risk awareness and crisis fitness to be able to deal with extraordinary events.[108] Fortunately, this was not really necessary for decades, but today it seems to become more and more the order of the day.

2.2.3 Phase 3

Even if the power is back on and telecommunications are working again, the crisis is far from over. The subsequent Phase 3 will last weeks, months or even years, depending on the sector affected. For example, in industrialized agriculture, it is to be expected that millions of animals could die in Europe within a few hours.[109] [110]

Longer-lasting supply bottlenecks are therefore very likely, because of a loss of production, which can also affect vegetable production, for which many millions of people cannot simply be recompensed. Added to this are the many transnational dependencies in supply logistics.

One particular bottleneck could be packaging materials. If these are not available, for example because of serious production stoppages, products can no longer be packaged and put into circulation as usual.

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102 Cf. https://blog.alertswiss.ch/de/rubriken/vorsorge/notvorrat/. Accessed on 23.10.2023.
103 Cf. https://www.bbk.bund.de/DE/Warnung-Vorsorge/warnung-vorsorge_node.html. Accessed on 23.10.2023.
104 Cf. http://zivilschutzverband.at/de/aktuelles/33/Bevorratung-Checkliste. Accessed on 23.10.2023.
105 https://gfkv.org. Accessed on 23.10.2023.
106 https://www.krisenfit.jetzt. Accessed on 23.10.2023.
107 https://www.schritt-fuer-schritt-krisenfit.de. Accessed on 23.10.2023.
108 Cf. Alltagsrisiken: Internationale Studie zeigt geringe Risikokompetenz in der Bevölkerung. https://www.ots.at/presseaussendung/OTS_20230915_OTS0107/alltagsrisiken-internationale-studie-zeigt-geringe-risikokompetenz-in-der-bevoelkerung-bild. Accessed on 23.10.2023.
109 Cf. SRF-Blackout Thementag – Zusammenfassung – Landwirtschaft. https://www.saurugg.net/2017/blog/stromversorgung/srf-blackout-thementag-zusammenfassung. Accessed on 23.10.2023.
110 Cf. Auswirkungen eines großflächigen und langandauernden Stromausfalls auf Nutztiere in Stallhaltungen. https://www.saurugg.net/2021/blog/krisenvorsorge/auswirkungen-eines-grossflaechigen-und-langandauernden-stromausfalls-auf-nutztiere-in-stallhaltungen. Accessed on 23.10.2023.

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The expected widespread failure of refrigeration equipment in many supermarkets would have an enormous impact on the supply of goods to be refrigerated.

In our highly optimized just-in-time logistics, there is a multitude of possibilities why the entire chain could come to a standstill or even fail. The Austrian Complexity Science Hub (CSH) Vienna, for example, warned of this at the beginning of the Covid pandemic. The collapse of entire industries was possible if individual links in the chain failed [cf. CSH (2020)]. The war in Ukraine was assessed similarly critically [cf. CSH (2022)], even if severe disruptions have not yet occurred.

The expected recovery times will therefore take much longer than many have expected. This means that many areas of work will not be able to restart until the basic emergency food supply has been secured again.

The expected recovery times will therefore be significantly longer than many have assumed to date. Thus, the resumption of many areas of work will also only be possible once the basic emergency food supply has been secured again.

2.3 What can be done?

In the short term, only preparation for such a possible event seems to make sense, which also applies in general: prevention, protection and security are important, but not sufficient. We need "both/and" thinking here as well: We should be able to deal with unexpected events [cf. Weik (20102)] and manage them. This applies to all levels and areas. For example, preventing cyber-attacks is enormously important, yet a disaster recovery plan is essential, even if it is always hoped that it will never be needed. Just as in IT, only a good backup strategy protects against data loss, carefully planned and built-up reserves at all levels are essential for expected large-scale failures due to blackouts.

Hope alone is not enough. We are carrying out the biggest infrastructure restructuring of all time with our hearts open and without a safety net. This could turn out to be a fatal mistake.

The most important step begins in your own four walls: To be able to supply oneself and one's family self-sufficiently for at least 14 days by stockpiling. This includes at least two liters of water per person per day for at least several days (phases 1 and 2). After the power outage, cooking can be resumed, but not shopping. Foodstuffs such as noodles, rice or canned goods are therefore needed in addition to the supplies already available for 14 days. The same is true for essential medications, baby and pet supplies. Flashlights, a battery-powered radio, garbage bags and other essentials. Simply, everything one would take along for a two-week camping vacation [cf. Erlhofer (2023). p. 657ff].[111]

This basic provisioning is essential so that production and logistics can be ramped up again as quickly as possible. After all, if people can no longer provide for themselves, they will not be able to get to work to get production and systems up and running again. Broad self-provisioning among the population (=personnel) is therefore an essential prerequisite for being able to cope with such a scenario in the best possible way. This applies in particular to those organizations and companies that have to maintain emergency operations in such a case, i.e. also to the energy industry. On the other hand, no one can help millions of people if they themselves are affected.

2.3.1 Organizational measures

Building on self-provisioning, the necessary organizational measures can be taken. The first step begins with raising the awareness of the company's own personnel in order to initiate their own precautions. Secondly, comprehensive considerations must be made as to how the necessary communication can be ensured in the event of a blackout. This can often only be achieved through offline plans, i.e. prepared agreements that are available in written form and must be in the minds of the employees. The key personnel must know what to do if no one can be reached, or how a replacement and supply function, if emergency operations have to be maintained.

Alerting, as is usually the case, will not work as a rule since most telecommunications systems will fail within a few minutes of a power outage. When considering the availability of personnel, particular consideration must be given to personal circumstances, such as distance from the workplace or other obligations, such as caring for persons in need of care, functions in community crisis teams or emergency response organizations. It must also be clarified how long the available resources, such as the amount of fuel for emergency power generators or water and food, are sufficient for emergency operation, since

111 Cf. https://www.saurugg.net/leitfaden oder https://blog.alertswiss.ch/de/rubriken/vorsorge/notvorrat (Schweiz) oder https://www.bbk.bund.de/DE/Warnung-Vorsorge/warnung-vorsorge_node.html (Deutschland) oder http://zivilschutzverband.at/de/aktuelles/33/Bevorratung-Checkliste (Österreich). Accessed on 23.10.2023.

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without appropriate preparations it is unlikely that supplies will be available from outside. This goes all the way to restart plans, in which it is necessary to consider what requirements are necessary to be able to resume orderly operations at all.
As a rule, resumption of operations is only possible and sensible in phase 3 when telecommunication is sufficiently guaranteed again. That is, when the company's own employees can be reached by telephone again. After all, no coordination with customers or suppliers can function without telecommunications anyway. On the other hand, the basic supply of food must first be ensured again before other things are needed once more.

2.4 Summary

A large-scale power blackout is inconceivable to many people because they have not experienced such an event before. At the same time, there is no such thing as 100 percent certainty, especially when such fundamental and often non-systemic changes take place during ongoing operations as described in the first section.

A modern society should therefore also be able to answer the question "what if." So far, too many decision-makers and also the population rely on the principle of hope. That is important, to be sure, in order not to fall into fatalism. But if that is all with which to counter a possible event, it becomes very difficult to deal with such a possible surprise.

The reasons for this are complex. For one thing, the necessary error culture to deal with problems openly and transparently is often lacking. On the other hand, the political debate about the necessary energy transition is often conducted ideologically, with blinkers and little technical understanding. The additional polarization (either-or thinking) prevents any constructive discussion. From the technical side, on the other hand, there is often a lack of contradiction. This may be due to organizational dependencies or because one does not want to be labelled as an "eternalist".

Similar phenomena can also be observed in crisis preparedness. Inadequate precautions are usually admitted only behind closed doors. As a result, there are often large gaps between official statements and the actual situation. Although similar actions are taken everywhere, there is often the assumption that things must be better in other areas and that all the necessary precautions have certainly been taken there. Thus, too many unfoundedly rely on others. A large part of the population makes the unrealistic assumption that the state will take care of them in such a case.[112]

A possible and even very realistic blackout would therefore turn our highly technical and electricity-dependent society upside down within a very short time. While in the case of the Covid pandemic there was still a certain lead time and all infrastructural services could be maintained, in the case of a blackout total standstill occurs from one moment to the next. Prompt total chaos can only be mitigated by appropriate individual and organizational preparations.
This often requires only a manageable amount of effort: personal precautions for at least 14 days and corresponding organizational schedules that also function largely without technical means of communication. This can usually avert a lot of damage. But knowledge alone is not enough. We must also act quickly accordingly.

112 Cf. Krisenvorsorge: Die österreichische Bevölkerung setzt auf den Staat, weniger auf Eigenvorsorge. https://viecer.univie.ac.at/corona-blog/corona-blog-beitraege/blog114. Accessed on 23.10.2023.

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born in 1955 in Saarland, began an officer's career in the German armed forces. After completing his studies (Diplom-Pädagoge), he went through assignments at all levels of command up to the ministry. to the ministry. In two assignments, he was deployed in France for a total of eight years. France. Most recently, he was back in Saarland in the Landeskommando as Chief of Staff. chief of staff for civil-military cooperation, among other things. among other things.

Even after his retirement, he was intensively crisis and disaster management. For example, he supported the Saarland Foreigners Authority in the refugee crisis 2015 - 2018.

Power supply, power failure, blackout and crisis preparedness became defining topics for him. He shared his knowledge in lectures at the Academy for Crisis Management, Emergency Planning and Civil Defense (AKNZ) of the Federal Office of Civil Protection and Disaster Assistance (BBK). In addition, he has supported the Saarpfalz district since 2013 as a volunteer advisor in the power blackout working group. as an honorary advisor in the power blackout working group. His focus there was on the "Recommendations for action and recommendations for the population's own precautions". the population", including informing the mayors and the population. His book "Blackbox Blackout" was published in 2023.

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