Transnational infrastructure vulnerability: The historical shaping of the 2006 European “Blackout”

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Abstract

The “European Blackout” of 4 November 2006 is a key reference in current debates on transnational electricity infrastructure vulnerability and governance. Several commentators have observed that to understand what happened, one must look at history. Our paper answers this call and demonstrates how historical choices, path dependencies, and ways of dealing with these afterwards, have shaped Europe’s electric power infrastructure and its vulnerability geography. We show that the decentralized organization of transnational electricity infrastructure and governance, often blamed for present-day power grid fragility, was informed by reliability considerations that still count today. We also address the (meso)regional logic of the failure, foregrounding how stakeholders from different parts of Europe historically chose to collaborate in different ways, with due consequences for the 2006 disturbance and other recent blackouts. Finally, the paper observes that today’s notion of transnational electricity infrastructure vulnerability, supposedly demonstrated by the 2006 blackout, is highly contested as many stakeholders find the system extremely reliable.

1. Introduction

For decades most literature about energy-related vulnerability and risk has been concerned with import disruptions (Plummer, 1981; Andrews, 2005; Reymond, 2007; Weisser, 2007; Gnansounou, 2008; Gupta, 2008; World Energy Council, 2008), financial risks (Awerbuch, 1993, 2000; Vine et al., 2000; Mills, 2003; Bolinger et al., 2006; Sadeghi and Shavvalpour, 2006), pollution (Lave and Silverman, 1976; Proops et al., 1996; Syri et al., 2001; Haas et al., 2008), or accidents (Perrow, 1984; Hirschberg et al., 1998, 2004; Sovacool, 2008) involving primary energy sources—mostly oil, gas, coal, nuclear, and renewables. A recent body of scholarship adds energy vulnerabilities associated with energy supply as critical infrastructure. This concept spotlights the infrastructure dimensions of energy—electric power grids, gas supply networks—and the massive societal and economic dependency on uninterrupted energy infrastructure services. In this emerging literature, blackouts, next to terrorist attacks, are routinely cited as key examples demonstrating the criticality of modern infrastructure. Moreover, electric power networks are counted among the most “critical” of all critical infrastructure (Lukasik, 2003, p. 208; Perrow, 2007, p. 11; Kröger, 2008). They merit specific inquiry (e.g. Amin, 2002, 2005; Watts, 2003; De Bruinije, 2006; Gheorghe et al., 2006, 2007) and are prioritized in Critical Infrastructure Protection programs (PCCIC, 1997; Commission of the European Communities, 2005, 2006a; Fritzon et al., 2007).

The so-called “European Blackout” of Saturday 4 November 2006 stands out as a particularly vivid illustration of transnational infrastructure vulnerability with allegedly Europe-wide implications. The impressive speed and geographical reach of the event have been well documented in several investigation reports (E.ON. Netz, 2006; Bundesnetzagentur, 2007; UCTE, 2006b, 2007; ERGEG, 2007). It was set off by a planned disconnection of an E.ON. Netz double circuit, extra-high voltage line over the Ems River in Northern Germany to allow the passage of a large cruise ship to the North Sea. Other lines were to take over the load as previously in similar situations. Yet this time, a combination of events caused sufficient overload in a tie-line between the E.ON. Netz system and the neighbouring RWE system to trigger that line’s automatic protection. It shut down at 22.10:13. Then, as electricity sought alternative pathways, in an astounding 14 s, a cascade of power line trippings spread through Germany. In the next 5 s, the failure cascaded as far as Romania to the East, Croatia to the South-East, and Portugal to the South-West. Synchronization of the continental network was lost; overloads and underloads proliferated throughout the subcontinent causing more lines and generating units to fail. The incident had now affected electricity supply in about 20 European countries. Supply was cut selectively to some 15 million households. Via the Spain-Morocco cable the disturbance reached Morocco, Algeria and Tunisia.
where lines tripped and consumers were left in the dark. If an incident in Northern Germany can make the lights go out in Tunisia within a matter of seconds, we may speak of a noteworthy transnational critical event. Moreover, the blackout became an important reference in transnational governance debates as European Union (EU) policy makers asserted that Europe's power grids are 'highly vulnerable' and in need of more centralized forms of governance.

Several observers and official investigation reports contend that to understand what happened on 4 November 2006, or 4/11,1 one must look at history. Yet so far, they have discussed this history only in extremely general terms, focusing instead upon short-term causes and measures (as they should). Moreover, these generalized historical interpretations tend to be politically laden as they tie into current changes in the transnational governance landscape, notably the increasing role of the EU in energy and electricity issues. In this paper, therefore, we use novel historical research to investigate the long-term shaping of 4/11. We look at how historical choices, path dependencies, and subsequent ways to deal with these, have shaped Europe's electrical vulnerability geography. We highlight two aspects of this geography in particular: (1) the decentralized organization and governance of Europe's electric power grids, on which recent EU documents tend to blame the blackout and (2) the (meso)r-regional logic of the failure, highlighting how stakeholders from different parts of Europe historically chose to collaborate in different ways with due consequences for their involvement in, or exclusion from, 4/11. In addition, we shall raise questions regarding the interpretation of the blackout as a demonstration of either electricity infrastructure ‘vulnerability’ or ‘reliability’, which inform present negotiations on transnational electricity infrastructure governance.

While adding historical perspectives to the analysis of 4/11, we hope they may also inform the broader inquiry of transnational infrastructure vulnerability. Before proceeding, however, we will briefly address the relevance and current state of European power grid historiography.

2. 4/11, root causes, and power grid historiography

We already noted that the relevance of history for understanding 4/11 has been acknowledged repeatedly. Asking how the 2006 blackout could happen again after the wake-up calls of the large 2003 blackouts in the US/Canada and in Italy (affecting Austrian, French, Slovenian and Swiss systems as well), Bialek (2007, p. 54) notes that “to answer why the blackouts have happened, we have to look at the developments of the last 50–60 years”. The authoritative international organization of continental European TSOs, the Union for the Coordination of Transmission of Electricity UCTE (established 1951; terminated and merged into the European Network of Transmission System Operators for Electricity ENTSO-E in 2009), likewise places the event prominently in a historical context in its 4/11 final investigation report. Both Bialek and the UCTE report argue that the European interconnected transmission system was originally designed for the past situation of self-contained utilities with weak tie-lines to neighbouring networks in a largely bilateral governance model. The era of liberalization, however, brought about commercial long-distance electricity trade between national subsystems, causing a bulk use of power lines for which they were not designed. This “fundamental change of paradigm” (UCTE, 2007, pp. 5 and 13) made the system vulnerable to disturbances. The same observation was made after the infamous Italian blackout of 2003 (UCTE, 2004a, p. 3).

This general observation is as far as the historical analysis goes. Having noted how historical processes shape today's infrastructure vulnerability, investigation reports and other analyses focus on short-term ‘root causes’ and short-term solutions (see also Chen et al., 2007; Johnson, 2007; Li et al., 2007, who miss the historical dimension altogether). The causes of 4/11 were many. Indeed, the UCTE final investigation report reads like a case of Charles Perrow’s (1984) Normal Accident Theory, where unanticipated combinations of multiple events in complex systems ultimately produce failure. Here we will do no more than briefly list this cavalcade of interacting events (UCTE, 2006b, 2007), including environmental, licensing, and construction time barriers to strengthening the grid; strained operation of the grid near its maximum capacity as emerging ‘common practice’ among operators; a number of extra-high voltage transmission system elements being down for scheduled maintenance immediately prior to the disturbance; temporarily adjusted settings of several E.ON. Netz substations (normal procedure yet crucial in retrospect); German weather conditions producing high wind power output, causing particular high flows from Germany to the Netherlands and Poland; an overall continental grid condition of long-distance flows from North-Eastern to South-Western Europe; late changes in the scheduled power line shutdown to facilitate the cruise ship passing; failure of E.ON. Netz to perform repeated numerical analysis of the N-1 secure state of its network (checking that one failing element will not produce a cascade); operation of other lines near their maximum capacity after the shutdown; fluctuations in the grid (which are common) increasing the strain even more; discovery that a crucial tie-line (the one that would trip first) between the E.ON. Netz and RWE transmission zones had lower protection settings on the RWE side than on the E.ON. Netz side; and response to this situation, including a dispatcher change of specific substation settings that slightly increased, instead of decreased, the load on the critical tie-line. Under the accumulated circumstances, this was sufficient to cross the lower protection threshold on the RWE side of the mentioned E.ON. Netz-RWE tie-line and automatically trip the line. Then a cascade followed, each trip line increasing the burden on others, leading to new failures as cascades do (Nedic et al., 2006).

While these immediate factors have been scrutinized and are leading to new security measures, the long-term developments that produced the setting for today's transnational vulnerabilities as exposed on 4 November 2006 have not been addressed in any detail. This paper will therefore delve deeper into European power grid history. We believe that a scholarly historian's take on this subject is warranted not only because it has been lacking, but also because existing references to this history in recent debates on Europe's power grid vulnerability have a sharp political edge, leading to radically different interpretations by power sector representatives and EU policy makers in the context of a changing transnational governance landscape.

Devising a history of the European power grid, however, is not a straightforward exercise. The first problem is that academic historical scholarship on electricity networks – as well as other infrastructure – has overwhelmingly addressed national or sub-national developments (for reviews see Van der Vleuten and Kaisjer, 2005, 2006; Lagendijk, 2008, pp. 20–30). Studies looking beyond a single country usually took a national comparison format (Hughes, 1983; Kaisjer and Hedkin, 1995; Varaschin, 1997; Van der Vleuten, 1999; Milward, 2005), implicitly maintaining the (sub)national as their unquestioned unit of analysis. With very few exceptions, histories of electrification looking at networks

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1 Using 4/11 for shorthand, we acknowledge that the infrastructure-related terrorist attacks of 11 September 2001 (9/11 in US spelling) and 3 March 2004 (also known as 3/11) of course were much graver.
A second difficulty involves the very concept of a “European” power grid. Notions of “Europe” vary with time and political paradigm. Surely a serious historical investigation cannot take for granted the dominant Cold War meaning of “Europe” reserving the term for Western countries, which was the original context for the development of the UCTE, set up by the Marshall Funds distributors in the Organization for European Economic Cooperation OEEC. By the same token it cannot uncritically equate “Europe” to the EU, a meaning that is rapidly gaining currency in political and popular discourse and as the scholarly category to which all analysis must converge. Instead a European power grid history needs to inquire openly what “electrical Europe” came to look like. It needs to acknowledge that plans for such a grid since the 1930s routinely stretched from Portugal to Russia, and that indeed by the late 1960s power lines electrically linked Northern Scandinavia to Southern Italy and Lisbon to Moscow. At the same time this pan-European network was far from homogeneous. Such a wide scope is needed also to understand why 4/11 affected Portugal and Tunisia, but not Sweden and Russia.

Only recently a transnational perspective in scholarly technological history (Misa and Schot, 2005; Van der Vleuten, 2008) and a sustained research effort into European infrastructure history produced work on European electricity infrastructure history that takes these problems into account. In the present paper we build in particular on Lagendijk’s (2008) Ph.D. thesis work in the archives of multiple international organizations, which we reinterpret and supplement for the purposes at hand. Unless otherwise noted, the following historical information is taken from Lagendijk (2008).

3. Centralized versus decentralized system building

An initial theme we wish to investigate historically concerns the decentralized (from a European perspective) organization and governance of Europe’s electric power infrastructure. In recent years, EU spokespersons and some analysts have problematized this decentralized organization. In response to 4/11, EU Energy Commissioner Andris Piebalgs stated that “these blackouts ... are unacceptable” and “confirm the need for a proper European energy policy. Energy security is better delivered through a common European approach rather than 27 different approaches” (Commission of the European Communities, 2006b). He then proposed an EU-level regulator, formally binding legislation, and perhaps even a European priority interconnection plan (Commission of the European Communities, 2006c). An investigation report by the European Regulators Group for Electricity and Gas ERGEG, established in 2003 on the initiative of the European Commission to assist the introduction of EU legislation in Member States, further confirmed that “the events of November 4 uncover a legal and regulatory gap in Europe’s electricity market” and that EU interference was needed (ERGEG, 2007, p. 4). These observations paved the way for new EU legislation and even a new EU-level regulator that have since been established or are well under way (Piebalgs, 2009; Commission of the European Communities, 2009). Academic analysts have posed similar arguments, though not necessarily equating their calls for centralizing electricity infrastructure governance with EU interference (e.g. Gheorghe et al., 2006, 2007).

How, then, did this decentralized organization come about, and was/is it really a problem? In the following we highlight that this decentralized organization was the outcome of a long struggle, in which centralization and top-down organization of a European power grid were repeatedly pushed as an option. Yet, in notable contrast to present-day EU argumentation and initiatives, centralization quite deliberately became a road not taken for both economic and reliability reasons.

3.1. Setting the stage

We start here by noting that the issue of national compartmentalization in electricity supply was absent in the earliest period of cross-border collaboration, roughly before the First World War. High voltage transmission had been developing rapidly since the 1890s, but was not yet interpreted in national, let alone continental, contexts. Early cross-border power lines served local or (micro)regional purposes. Since national borders were not yet key obstacles, such local or micro-regional systems were established within as well as across political borders. Neither were state governments important players yet. Some important cross-border systems were set up by (now obsolete) financial holding companies established by banks and equipment producers like AEG, Brown Boveri & Cie (later merged into ABB and Alstom), and Siemens. For instance, in the 1890s a new hydropower plant at the binational town of Rheinfelden at the River Rhine supplied power to both the German and Swiss sides of the border; from 1906 it also powered Guebwiller in Alsace, France, by a 40 kV line. In the same year an export-oriented plant at Brusio, Switzerland, started to feed Alpine waterpower into Northern Italy via 23 and 55 kV lines. In other cases, existing utilities connected across borders. For instance, from 1915, surplus hydropower from Sydkraft (currently E.ON. Sverige) in Southern Sweden was exported to the thermal power-based system of NESA (currently DONG Energy) in North-Eastern Denmark using a 6 MW, 25 kV AC submarine cable under the Sound, paid for by the receiving power company (Kaajer, 1997, p. 6).

In the years between the World Wars, the historical context alluded to in current discussions started to emerge. While several existing electric utility owners – large and small commercial companies, municipalities and other lower governments, rural cooperatives – competed for a position in the booming electricity sector (e.g. Van der Vleuten, 1998, 1999, 2010), two important new players joined the game. First, the war witnessed not only state governments introducing obligatory border passport requirements that stayed in place after the war, but also a steep rise of economic nationalism. State governments increased their grip on the electric power sector through legislation on prices, hydropower resource development, electricity export restrictions, developing electricity as national service, and national power grid planning (Lagendijk, 2008, pp. 56–57). In countries where such acts were not accepted, often they were still drafted, hotly debated, and influenced power grid developments (e.g. Van der Vleuten, 1999). The nation-state, in short, became a potent category for electrification.

Second, this development was contested not only by existing players like private, municipal, or cooperative utilities, resisting state interference with varying degrees of success (often national grids only emerged after the Second World War). Electric nationalism was also countered by a new electric internationalism (compare Schot and Lagendijk, 2008). In the first half of the 1920s, new international organizations such as the International Council on Large Electric Systems CIGRE (established 1921), the Union of Producers and Distributors of Electricity UNIPEDE (established 1925, currently EURELECTRIC), the World Power Conference (established 1924, currently World Energy Council), and also the League of Nations discussed the proliferation of electric nationalism and worked to enable international electric power exchanges. In these settings, around 1930 ideas emerged for a European
electricity grid, which we would today call a “supergrid” (e.g. Higgins, 2008). These included plans like George Viel’s 1929 scheme of 3000 km of 400 kV grids stretching from Trondhjem, Norway in the Northwest to Lisbon, Portugal in the Southwest and via Lviv (now Ukraine, then Poland), Vilnius and Riga into Russia in the East. Also Oskar Oliven’s 1930 scheme of 9750 km of 200/400 kV lines stretched from Lisbon and Trondhjem to Rostow, Russia. The motives for such continental collaborations included the rational use of resources (not least inserting large-scale hydropower resources into Europe’s energy supply) and providing emergency assistance through interconnected systems. Finally, such engineering schemes were connected to a Europeanist political agenda. Doubtful about the political road to a United States of Europe, Europeanists captured infrastructure as a low-key means to integrate Europe economically and culturally. For them, a European high voltage grid would make Europe’s scattered energy sources available to all, modernize the economy, create mutual interdependence preventing war more effectively than paper treaties, and even create a “spiritual bond” among Europe’s peoples.

However, the politically preferred model of top-down construction of a European power grid, backed by political will and international financing, became a road not taken. Taking a power company perspective, representatives from the electricity sector preferred a gradual approach of building economically viable utility and perhaps national networks that could be connected across borders on a case by case basis. Moreover, in a context of economic depression and increasing national strategic interests, international financing plans for a European power grid were torpedoed. The Europeanists became isolated, and the international push for supranational electricity system building transformed into an international regulatory approach by the above-mentioned international organizations. System building activity was left to power companies and national governments.

Importantly, while national developments became a focal point of electrification, cross-border interconnection and electricity exchange initiated by electric utilities seeking immediate economic or reliability gains grew steadily in its shadow. Already by the mid-1920s the first electric power import/export statistics showed that, despite the lack of an integrated network, individual utilities in Austria, Czechoslovakia, Denmark, France, Germany, Finland, Italy, Lithuania, Luxembourg, the Netherlands, Norway, Poland, the Sarre region (a League of Nations protectorate between 1920 and 1935), Sweden, and Switzerland engaged in (micro)regional cross-border exchanges (Lagendijk, 2008, p. 45).

3.2. Establishing transnational collaboration

In a third period, roughly covering the Second World War and Cold War, the confrontation between a top-down and gradual road to a European grid was repeated twice. The renewed political push for a European supergrid came first from Nazi Germany, depicting infrastructure as a form of Grossraumtechnik serving to integrate their envisioned Neuropa (Maier, 2006). Work on a pan-European underground High Voltage Direct Current (HVDC) grid interconnecting the envisioned Reich from London and Oslo to Barcelona and Stalino (currently Donetsk, Ukraine) was frustrated by the course of the war. New cross-border High Voltage Alternating Current (HVAC) connections to e.g. the Netherlands and Austria were built, but served the more mundane motive of feeding foreign energy sources into the German war economy. After the war, in the context of rebuilding a war-torn Europe, United States Marshall Planners also pushed the idea of a top-down, supranational, jointly owned and financed European power grid (Lagendijk, 2008, p. 126). They saw transnational infrastructure as a means to rapidly rebuild an integrated Western Europe and at the same time construct an economic and military barrier to the spread of communism.

Yet again, national and sector interest (since the war regularly represented by ministers responsible for nationalized utilities) preferred to invest in national or utility infrastructure, and less so in cross-border cooperation (Lagendijk, 2008, p. 127ff.). The transnational collaboration model developed in the UCPTE zone, the part of Europe where 4/11 happened, was prepared in the Organization for European Economic Cooperation OEEC (established 1948, currently OECD), the organization where European governments negotiated with the US on distributing Marshall Plan funds. Governments and power sector representatives managed to direct these funds towards national power system development; the Marshall Plan’s projected International Power Program failed to take off. As for cooperation between national systems, the OEEC electricity committee saw no need for a European dispatch centre or European/international ownership of plants and grids. Instead, “discussion of possible interchanges … [was to be] left to the free negotiations of the utilities concerned” (OEEC, 1950, p. 24). Like in the 1930s, the idea of “integrating Europe” was downplayed, while economic and efficiency gains for the power sector were put forward as lead motive for collaboration: interconnecting an economic mix of power sources (thermal and hydropower plants) and sharing emergency power generating capacity, so that investment costs for participating utilities could be reduced. Such advantages were first and foremost to be found within national borders, but might also apply to cross-border collaboration (Van der Vleuten et al., 2007, p. 335).

This preference materialized in the OEEC-initiated West European power pool organized by the UCPTE, established in 1951 to make the “most effective use of the means of production and transport of electric energy in the countries of the members” as article 2 of the 1954 statutes read (UCPTE, 1971, annex). This supposedly demanded a decentralized approach: “Decentralization is indispensable for economy, security, and continuity of supply on the regional level” (UCPTE, 1976, p. 153, our italics). The organization was set up accordingly as a non-governmental, coordinating body of utility representatives (and delegates of public administrations) who participated on a voluntary basis. Participating utilities remained fully in charge not only of network building and supply in their own supply areas, but also of financing, building, and operating cross-border connections, of which they maintained full ownership. In this scheme, utilities built cross-border power lines and negotiated exchange contracts when it made sense from economic or reliability perspectives. The UCPTE provided the necessary coordination and facilitation and obtained a mandate to organize emergency assistance across borders.

The workings of the organization changed repeatedly, particularly in the era of Europeanization and re-regulation, but before 4/11 its decentralized model of transnational governance largely stayed in place. This led to the development of the continental power grid we have today, and the patterns of exchange on it. In some areas, utilities were international-minded and developed grids and exchanges accordingly, as in the case of extensive Austrian and Swiss power imports and exports. In other parts of Europe, cross-border grids and exchanges remained minor, as the European Commission later complained repeatedly: around the turn of the Millennium, countries such as Italy, Greece, Spain, Portugal, the UK and Ireland even had an ‘interconnection capacity’ – the import capacity relative to domestic generating capacity – below 5%. For other countries (e.g. France, Germany) it was about 10%, while front runners reached over 20% (Verbong, 2006). As for usage of existing capacities: The ratio of cross-border electricity flows to European electricity generation (in this calculation including all except former Soviet Union countries)
increased from 5% in 1980 to 7% in 1992 and 9% in 2004, suggesting the continued dominance of domestic electricity circulation (Lagendijk and Van der Vleuten, 2009; Energy Information Administration, 2009).

3.3. Interpreting 4/11

Important for our interpretation of 4/11 and transnational electricity infrastructure vulnerability, the UCPTE from the beginning positioned decentralized organization simultaneously as an economic and a reliability asset, not a threat as present-day EU documents tend to argue. UCPTE spokespersons found that participating utilities in the collaboration knew the particularities of their own systems much better than any centralized organization could ever hope for. Reliability governance should hence be decentralized: In line with the decentralized mode of constructing and managing Europe's power grids, each TSO in the affected zone was responsible for taking security measures to counter power imbalances in its specific supply area (UCPTE, 1971, 1976). As it was put in the mid-1970s: "A European centralized control centre ... does not exist and could not function properly, because it would not be able to see the needs of the separate regional networks" (UCPTE, 1976, p. 188). This argument was used until very recently. As the UCTE final investigation report of the 2003 Italian blackout stated, "the blackout and subsequent investigation has cast no doubt on this [decentralized] model in principle. On the contrary, the lack of a [decentralized] grid operator's empowerment and independence could be identified as a potential security risk" (UCTE, 2004a, p. 10).

On 4/11, then, the failure triggered a decentralized response by Transmission System Operators, executing TSO-specific defence and restoration plans including automatic and pre-programmed cutting of selected power users (load shedding) within a matter of seconds, and subsequent automatic or manual starting or shutting down of generation capacity within minutes. Each TSO acted according to its own preset procedures and plans; little additional coordination took place (UCTE, 2007, Chapter 3). According to TSO spokespersons, this decentralized response worked extremely well in the case of 4/11: the cascading failure was quickly contained and for the large majority of consumers, the lights actually stayed on. Areas that were shut off to achieve this were back on-line mostly within half an hour (and the complete system within 2 h). The UCTE 4/11 final investigation report therefore concluded, in marked contrast to EU Commissioner Piebalg cited above, that "the decentralized responsibilities of TSOs have demonstrated their efficiency" and thus a "Europe-wide blackout could be avoided" (UCTE, 2007, p. 6, our italics).

Our brief historical overview thus suggests that the decentralized organization of Europe's electric power infrastructure was certainly a deliberate choice in the past for both economic and reliability reasons: decentralized and informal collaboration was repeatedly preferred to the centralized alternative, and sector advantages (not least an economic mix of power sources and reliability gains) in specific bilateral projects to broader European integration politics served as lead motives for cross-border electrical cooperation. This observation suggests that researchers need to carefully distinguish and evaluate these motives in present-day discussions, for in the current era of EU-led Europeanization they are often conflated.

Moreover, it suggest that the very perception of Europe's decentralized power infrastructure and governance as "vulnerable" is contested and bound up with current re-negotiations of transnational electricity infrastructure governance, which finds the EU and the power sector at cross purposes. We follow up on this theme elsewhere (Van der Vleuten and Lagendijk, 2009); here it suffices to note that the interpretation of 4/11 is contested and politically laden.

4. Regional dynamics of electric integration

We now turn to a second aspect of Europe's electric vulnerability geography as exposed on 4/11. In the Cold War period described above, Europe was electrically connected from Lisbon to Moscow and Trondheim to Naples. Yet this cross-border collaboration was concentrated in several transnational (meso)regions. Connections between these regions existed but were often relatively weak. In this section we examine this legacy from the 1950s and 1960s, and the ways it has been dealt with in later decades, thus providing a historical explanation for the spatial logic of 4/11.

The original UCPTE cooperation, it should be remembered, included only Austrian, Belgian, Dutch, French, Italian, Luxembourg, Swiss, and Federal Republic of Germany utility representatives. Geographically it embraced the integration zone of the six founders of the European Coal and Steel Community (established 1951) and later the European Economic Community (established 1957), two direct forerunners to the European Union, plus Austria and Switzerland. Utilities outside this zone established a number of other collaborations and associated interconnections, often taking the UCPTE as their example, but still – initially – choosing organizational independence from this Western European collaboration. The resulting fragmentations in Europe's electric power grid of the 1950s and 1960s are nicely captured in the representation of power exchanges in 1975 (Fig. 1).

In post-war Northern Europe, for instance, a Nordic political and economic integration process initially counted as a valid alternative to Western European integration. This translated in not only the establishment of the Nordic Council (established 1952) and the Nordic Passport Union (established 1954), but also – at the suggestion of the Nordic Council – the Nordic power collaboration Nordel (established 1963) to coordinate a Nordic power grid. The organization was set up in the decentralized and voluntary image of the UCPTE. Note that Nordel was not a technical necessity induced by the presence of sea straits between Scandinavia and continental Europe. As noted above, East-Danish and South-Swedish utilities had co-operated by HVAC submarine cables since 1915, a technology which had been greatly improved since, not least by the Swedish manufacturer Asea. The same goes for submarine HVDC cables, where Asea became a key player (Kajiser, 1997; Fridlund and Maier, 1996; Fridlund, 1999). Besides, even utilities in continental Western Denmark, sharing a land border with West-Germany, participated in Nordel. Rather than
technical necessity, the establishment of Nordel followed organizational considerations in a political context that did not – yet – accept the idea of European Integration as we know it today. A similar logic informed the separate development of the power sector on the British Isles.

In Southern Europe, similar collaborations emerged. Collaboration between French, Spanish and Portuguese utilities in the Franco-Iberian Union for Coordination and transport of Electricity UFIPT (established 1963) was again set up in the image of the UCPTE. In the South-East, the Cold War made cooperation through Yugoslavia tricky. Yet several stakeholders desired to make Yugoslavian hydropower resources available to countries west of the Iron Curtain. NATO, while blocking a number of other East-West links, supported the scheme that might draw Yugoslavia, after its break with the Soviet Union, closer into the Western world. A study project called Yugelexport evolved into cooperation via three interconnections to UCPTE partners by 1955 and eventually into SUDEL. In 1964, an organization associating Austrian, Italian, Yugoslavian (and since 1972 also Greek) utilities. Its formal aim was to exploit complementary power resources in member countries and improve mutual security of supply. Since the Yugoslavian power authority also collaborated with its neighbours in Hungary, Romania and Bulgaria, it became a prominent connector between East and West in Cold War Europe (SUDEL, 1984; Lagendijk and Schipper, 2009).

This leads us to the most significant fragmentation in Cold War electrical Europe, the so-called Iron Curtain, or, in this case, the Electric Curtain (Persoz and Remondeulaz, 1992). Central and Eastern Europe were drawn into the Soviet orbit via the Council for Mutual Economic Assistance (CMEA or COMECON, established 1949). Resembling the OEEC establishing the UCPTE in the West, the CMEA established the Central Dispatch Organization to coordinate the Interconnected Power Systems (CDO/IPS, established 1962) to foster electrical integration. Power plants in Czechoslovakia, the German Democratic Republic, Hungary, Poland, Western Ukraine, and soon Romania and Bulgaria were put in synchronous operation (Persoz and Remondeulaz, 1992). Finally, this collaboration was connected to a sixth electric collaboration region. The Soviet Union’s Unified Power System became a huge interconnection including the Latvian, Estonian, Lithuanian, Belarussian, and Ukrainian Soviet republics.

4.1. Forms of collaboration

As we know, these groupings changed form in later decades. Moreover, they developed several kinds of collaboration between them, as Fig. 1 also shows. We argue that the way in which this happened shaped the meso-regional logic of 4/11. This geography is roughly portrayed in Fig. 2.

As Fig. 2 shows, 4/11 – which started in the original UCPTE zone – did affect the Iberian Peninsula, the Balkans, much of Central Eastern Europe and, in a different colour yet still included in Fig. 2, parts of North Africa. It did not affect most of Scandinavia, the British Isles, the Baltic Republics, and the Commonwealth of Independent States.

The affected area obviously corresponds to the UCTE zone plus areas that operate synchronously, such as Western Ukraine, Albania, and Morocco, Algeria and Tunisia, jointly known as the Trans European Synchronously Interconnected System TESIS. Cascading failure, after all, is a property of synchronously interconnected networks. The areas outside the reach of 4/11 were connected to the TESIS zone, but in an asynchronous fashion, for instance by High Voltage Direct Current (HVDC) connection or pocket operation, both of which would halt cascading failure. What needs historical explanation, then, is why collaborating actors chose either synchronized or asynchronous connection to the original UCPTE grid where, much later, the system failure of 4/11 emerged. Different from generalized textbook theories on the pros and cons of synchronization, we interpret such choices as historically contingent, following different actor motives and negotiations in particular historic settings—with due consequences for Europe’s present-day electrical vulnerability geography.

Let us first consider the TESIS area. Within the UCPTE, parallel operation of power stations in one transnational, synchronized system had been the preferred mode of operation from the beginning and remains so today as further expansion is contemplated. From the 1950s UCTE spokespersons emphasised both economic and reliability advantages of synchronous cooperation. As for economics, the most important argument was exploiting an economic mix of power sources: an original aim of the UCPTE (explicitly stated in its 1954 statutes) was to eliminate losses of excess hydropower in post-war Europe. In a synchronously operated power pool, hydropower plants would no longer leave excess hydropower to go to waste. Instead all available water could be led through the turbines and fed into the power pool, instantaneously enabling a reduction in fuel costs in thermal power stations elsewhere in the system. Hydropower wastes had largely been eliminated in the UCTE zone by 1970 (UCPTE, 1976).

As for reliability, synchronous collaboration implied that any failure of a power station in the grid would be contained and counteracted in a matter of seconds by other generators in the pool. Such a power station failure would cause a drop in the system frequency, which by virtue of its correlation with the rotation speed of electromagnetic machines, would instantaneously reduce the number of revolutions of all turbines in the pool. Conversely, by virtue of the same relationship, the still operational generators jointly counteract a further frequency drop; the larger the pool, the more generators to stabilize the frequency, the less impact of failure. Furthermore, plant managers could then locally speed up their turbines and bring the frequency back to the standard of 50 Hz. In this way, “all production units in the synchronous system jointly counterbalance the disturbance of one power station, regardless if this power station is located in Lisbon, Palermo or Hamburg, le Havre or Vienna” (UCPTE, 1976, p. 167), an arrangement known as “primary control”. On the other hand, synchronous collaboration did entail a risk for a new type of disturbance in the form of cascading failure. Hence the UCPTE strategy of enlarging the synchronous cooperation zone while at the same time taking measures to prevent or contain cascading failure, such as the load shedding plans mentioned above.

Of the groupings established in the 1950s and 1960s, similar arguments led the South-Western UFIPT and South-Eastern SUDEL rapidly into synchronized interconnection to UCPTE partners. UFIPT members had done so already in 1964. The
SUDEL group eventually chose the same path. Inspired by the twin aims of exploiting the complementarity of hydro and thermal power stations and increasing reliability of supply, the partners initially constructed a separate SUDEL ring in Southern Austria, North-Eastern Italy, and Western Yugoslavia, operational in 1970 (SUDEL, 1984, pp. 16–17). Originally the ring could be connected to the UCPTE or the CD-O-IPS system at will: by 1970 the Yugoslavian partner operated 10 interconnections with CD-O-IPS partners and 10 with UCPTE partners (Lagendijk, 2008, p. 188, Table 5.2). From 1975 SUDEL chose synchronous collaboration with the grids of its UCPTE partners, which in 1977 was extended to Greece. This move was credited with great stability and quality improvements particularly for the Yugoslavian and Greek systems (SUDEL, 1984, p. 20). Both UIFIPE and SUDEL members became full UCPTE members in 1987.

The same happened with Central Eastern European countries in the 1990s (Persoz and Remondeulaz, 1992; Hammons 1997). The relevant historical context was the end of the Cold War. The power systems of four Central Eastern European countries had been synchronously connected to the Soviet United Power System since 1962; later, other national systems had been added. Connections through the Electric Curtain were rare, and either used HVDC technology or isolated AC links (pocket mode). The end of the Cold War, however, produced a political, economic and also electrical reorientation in Central Eastern and Eastern European countries. Polish, Czech, Slovak, and Hungarian power companies now contemplated synchronous connection to the UCPTE zone, seeking reliable and economic collaboration in anticipation of an economic boom and trade flows with Western Europe. In particular they hoped to replace power exports to the East by much more lucrative exports to Western economies. Several Western power companies and the European Union supported this move financially (the latter via the for instance “Poland and Hungary: Assistance for Restructuring their Economies”, or PHARE, program).

To facilitate this process, these four Central Eastern European power authorities set up the new association CENTREL (established 1992, terminated 2006) and by 1995 synchronised cooperation with the UCPTE zone started. From now on cooperation to the East happened by asynchronous links. CENTREL members gained full UCPTE membership in 1999 and CENTREL was terminated in 2006. Others soon followed. The Western-Ukraine power system continued to collaborate with the CENTREL system and synchronized with the UCTE system in 2002. After the turmoil of the Yugoslavian wars, also the Romanian and Bulgarian power sectors became full UCTE members in 2003 and were included in the UCTE synchronous operation in 2004 (Hammons, 1997; UCTE, 2004b; Feist, 2004). Europe’s Electric Curtain had moved eastward to the border of the United Power System of the late Soviet Union. In its footsteps followed the barrier to cascading failure and the events of 4/11.

Finally, parts of North Africa were affected by 4/11. The key historical choice here was for synchronous operation through an HVAC Spain–Morocco submarine interconnection in 1997. This happened despite the fact that asynchronous HVDC collaboration had also been considered. Indeed, the original HVAC cable had been designed for an anticipated change to HVDC operation, but this change was not implemented because HVAC connection was found to greatly improve the stability of the Moroccan system (Granadino and Amerdoul, 1999; Zobaa, 2004). Thus it was possible, on 4/11, that a frequency drop on the Spanish side triggered the underfrequency protection on the Moroccan side and tripped the submarine cable, interrupting Moroccan imports, and causing a deficit in the Moroccan system. Since the Moroccan system was interconnected synchronously to the Algerian and Tunisian systems, these were also drawn into the vulnerability space of 4/11 (De Montravel et al., 2007; UCTE, 2007, p. 39).

We conclude that a variety of reliability and economic motives in specific historical settings led power companies to collaborate synchronously in TESIS. Ironically, this synchronization came with a new kind of transnational vulnerability in the form of cascading failure as demonstrated on 4/11, a form of vulnerability which recently came to occupy centre stage in transnational governance debates.

4.2. Outside the 4/11 zone

Other electric power collaborations and individual power companies, by contrast, chose not to develop synchronous cooperation with UCPTE partners and as a result fell outside the 4/11 failure zone. Given the well-advertised advantages of large-scale synchronous operation, why did they choose differently?

In the North, Nordel partners developed intense collaborations with UCPTE partners as present-day power flows indicate. However, here is a historic legacy of choosing asynchronous couplings in the form of HVDC cables such as the Konti-Skan (Sweden–Denmark, 1961), Skagarrrak (Norway–Denmark, 1977), Baltic (Sweden–Germany, 1994), Kontek (Denmark–Germany, 1995), SwePol (Sweden–Poland, 2000) and most recently the NorNed (Norway–Netherlands, 2008) cables. These links do not transmit frequency disturbances; on 4/11, traffic on most of these cables was not affected at all. The Skagerak and Konti-Skan cables have emergency frequency regulation and even countered the disturbance, without any impact on the Nordel systems north of the HVDC links (UCTE, 2007, pp. 38–39). Thus 4/11 stopped at the Nordic HVDC barrier.

The historical choices and path dependencies behind this situation are best illustrated in Denmark. It had two Nordel partners until their merger in 2005, Eltrans for mainland Western Denmark and Elkraft for the densely populated islands of Eastern Denmark, where the capital Copenhagen is situated. Eastern Elkraft or its constituent organizations had historically collaborated in Nordel synchronically by HVAC submarine cables since 1915, as mentioned above. Plans for synchronous collaboration with German partners – implying synchronization between Scandinavia and Continental European systems – were discussed around 1960 but rejected as expensive and risky as they demanded a number of modifications to the existing system (Wistoft et al., 1992, p. 87). Direct collaboration with UCPTE partners was started only in 1995 with the Kontek cable to Germany using HVDC transmission. Eastern Denmark thus followed the Nordel pattern described above, and was not affected by 4/11.

The situation in continental Western Denmark, however, developed in an opposite way (Van der Vleuten, 1998, 1999). Eltrans and its forerunners, and in particular its most Southern member, had historically developed collaboration with Northern Germany’s power companies since the 1920s. To maintain this collaboration, the West-Danish grid built in the 1950s was synchronized with the continental UCTE system. In the following years, rather than changing this historic connection, the West-Danish power collaboration chose to maintain and expand it as the cheapest way to achieve the benefits of interconnection. Thus, when debating and developing cooperation with its more northern Nordel partners in the early 1960s (with its German partners at the negotiating table), it opted for the asynchronous Konti-Skan (and later Skagarrrak) HVDC cable, which was found to be cheaper than the AC connection and the associated synchronization of Nordel and UCPTE systems (Wistoft et al., 1992, p. 88). From a vulnerability perspective, these repeated historical choices left Western Denmark outside the protective HVDC barrier that
sheltered other Nordel areas from the impact of 4/11 as Fig. 2 indicates.

Other boundaries of 4/11 to the West and East followed similar historical processes. The UK has been connected to France by HVDC since 1961. Again this was a contingent historical choice: A study committee had earlier recommended a synchronous HVAC connection, merely noting HVDC advantages such as higher capacity, reliability of operation, independent control of the British and French networks, and providing a barrier to cascading failure. Yet intensive Swedish lobbying on behalf of HVDC cable supplier Asea won the French and British parties for a direct current connection (Fridlund, 1999, pp. 185–190). Almost half a century later, the present Interconnexion France England carrying some 2000 MW from France remained unaffected by the 4/11 events (UCTE, 2007, p. 39).

To the East, the Unified Power System in 2006 embraced the Commonwealth of Independent States and the Baltic Republics. Though synchronization with the UCTE zone has been under investigation since the 1970s (Persoz and Remondeulaz, 1992; Bondarenko et al., 2002), the players involved preferred asynchronous cooperation by direct current connection (either HVDC lines or back-to-back conversion stations) or operation of HVAC tie-lines in island mode (De Montravel et al., 2007, pp. 18–24). More recently, the UCTE also preferred this mode, as synchronous collaboration of the two blocks would reduce the transmission capacity available for the EU Internal Electricity Market, which was already congested. This stopped the cascading failure of 4/11.

The importance of specific historical choices and settings in this zone is well illustrated for the case of the Baltic republics (Högslöw, 2006). From the mid-1980s, a strong preference emerged in several Baltic States to disconnect from the UPS system and connect synchronously to the UCTE zone. Originally this move was partly motivated by environmental concerns: polluting and dangerous power sources were to be replaced by ‘clean’ Western power. In reality, it seems to have been a politically motivated strategy for achieving independence from Russia. For once political independence had been achieved, the interests in ‘clean’ Western power vanished. Instead it was decided to continue power exports to the UPS cooperation, which had traditionally been a major economic asset for Estonia and Lithuania. Contrary to the CENTREL countries, it was not expected that Western countries were interested in (‘polluting’) Baltic oil shale power or nuclear power from the infamous Ignalina power plant. This choice, again shaped by specific motives in a specific historical setting, had the unintended consequence of keeping the Baltic republics out of reach of 4/11.

4.3. Consequences for consumers

Historically specific contexts, choices, and path dependencies, not only shaped who was included and excluded in the 4/11 failure zone but also how the event influenced consumers in the affected area. As illustrated in Fig. 2, on 4/11 the TESIS grid split into four parts following tripplings of tie-lines between E.ON, Netz and RWE; internal E.ON. Netz lines; internal AGP lines in Austria; Hungarian–Croatian tie-lines; internal Hungarian and Croatian lines; and the Spain–Morocco cable (UCTE, 2006b, 2007).

The consequences for consumers depended on their location relative to these fractures. The condition of the overall system (again historically shaped, but we will not dwell on this here) prior to the event was one of structural electricity export from the North-Eastern zone, notably Northern Germany (not least wind power) to the Western and South-Eastern zones. The consequ-ences were most severe for the Western zone, losing some 9 GW previously imported from the North-Eastern zone and no longer able to match consumption. The resulting frequency drop caused the tripping of some 11 GW of generation units, increasing the imbalance between production and consumption to nearly 20 GW. This situation was countered by load shedding, that is, selectively cutting off consumers (and pump storage plants) in an automatic and pre-defined fashion to restore the balance between production and consumption. As a result, over 15 million households were left temporarily in darkness. The North-Eastern zone, by contrast, was left with a production surplus of over 10 GW causing a rise in frequency. The resulting tripping of generators (particularly wind power) lowered the surplus, which was further countered manually by decreasing generation output. In the South-Eastern zone, the split caused a modest deficit of 770 MW. The frequency stayed above the threshold and no consumers were plunged into darkness. The North-African zone, as we saw, had power shortages leading to load shedding and blackout (UCTE, 2007).

The infrastructure history aspect we want to highlight here is that the grid fractures producing these different zones occurred where the historically shaped interconnections were rather weak. For instance, the split between the Western and the Eastern zones roughly followed the legacy of the Cold War Electrical Curtain. East–West connections across the former curtain were relatively recent and weakly developed. Yet this legacy has been dealt with differently along the former Curtain, leading to slight deviations from the main pattern. Let us briefly situate this main break line historically.

Northern Germany, where the incident originated, is an exception: Here the break line followed the disconnected line facilitating the cruise ship passage close to the Dutch border and then several RWE-E.ON. Netz tie-line tripplings, which drew the most North-Eastern part of Germany and continental Denmark into the North-Eastern 4/11 zone. Further southeast, the Cold War legacy and ways it has been dealt with in the past two decades became important determining factors.

Firstly, the break line followed internal E.ON. Netz tripplings close to the former East German and Czech borders, served only by four cross-border tie-lines. Further south, the fault line crossed Austria, another deviation to the Electric Curtain logic, which is nevertheless explained by historical path dependency and choice. While after 1989 the connections of Austria’s centres of consumption in the East (such as Vienna and Graz) to its Czech and Hungarian neighbours were strengthened, the development of internal Austrian east–west linkages remained weak. Already in the late 1940s and early 1950s Marshall planners observed this problem and tried to strengthen the connection between Austria’s Western sites of Alpine hydropower production to its Eastern centres of consumption (Lagendijk, 2008, p. 171). For the last three decades an Austrian ring has been under construction, but completion in the southern part of Burgenland and east of Styria is delayed due to local and regional protest groups opposing the impact of transmission towers on the landscape and requesting underground cabling (ICF Consulting, 2002, p. 41; Commission of the European Communities, 2000, p. 97). Without this line, which is included in the EU Trans European Networks plan for electricity (TEN-E), only one 380 kV line is in place, which tripped on 4/11 (UCTE, 2006c, p. 72).

Further south, the break line followed the Slovenia–Hungarian border, not the Cold War Austrian/Italian–Slovenian border. The historical explanation is that the Yugoslavian wars had fragmented the SUDEL system. In the case of independent Slovenia (1991), active economic and technological cooperation was reinforced with Austria. After the wars tie-lines between former Yugoslav states were also repaired and eventually, in 2004, synchronous connection with the UCTE zone was restored (Feist, 2004). Yet the much needed upgrading was postponed (planned and anticipated...
in the EU’s TEN programme as EL-4) as efforts were redirected to building national systems in the new republics. On 4/11, therefore, the Slovenian–Croatian border was the weak spot. Finally, the break line ran across Croatia to the Mediterranean as the two long West–East linkages towards Serbia and Bosnia tripped. Similar types of historically shaped logics applied to the break lines between the North-Eastern and South-Eastern zones.

Again, historical contexts, choices, path dependencies, and ways to deal with these later, go a long way in explaining the logic of 4/11. The vulnerability geography of 4/11 can be analyzed in even further detail, as historically shaped grid topologies, and (im)balances between domestic production, imports, and consumption in individual supply areas resulted in different vulnerabilities. While only 3% of Dutch and 0.1% of Swiss consumers were shed, this was the case for 19% of Portuguese consumers. We will not go into further detail here, but merely note this aspect of the 4/11 vulnerability geography as pictured in Fig. 3. Finally, one may make similar analyses within individual countries. To our knowledge this has not yet been done.

5. Conclusions

As demonstrated repeatedly in this journal, historical studies may offer broader perspectives on present-day energy issues (e.g. Van der Vleuten and Raven, 2006; Verbong and Geels, 2007; Högselius, 2009; Lehtonen and Nye, 2009). In this paper we responded in particular to the call of Bialek (2007) and others that to understand 4/11 and present-day European electric infrastructure vulnerability, one must look at history. Based on recent and novel research we have provided historical content to fill the black box of history that figures in existing analysis of 4/11 and electric infrastructure vulnerability. We have thus provided a historical explanation of the 2006 European blackout, bringing into view how historical contexts and choices, path dependencies, and ways to deal with these later, shaped Europe’s electric vulnerability geography in terms of centralized/decentralized organization and meso-regional dynamics.

To cite just one example: when comparing the conversion of Central Eastern European TSOs to synchronous collaboration with UCPTE partners in the 1990s with the earlier decision of most Nordic TSOs not to do so (which as it turned out kept the latter out of 4/11), it will not do to isolate key variables such as transition costs or reliability considerations. In different historical contexts, similar considerations produced very different outcomes. Nota bene, we do not argue that synchronous cooperation in Continental Europe made the system more vulnerable than, say, the Nordic system that escaped 4/11, for the asynchronous barriers to cascading failure between the Continental and Nordic grids work in both directions. We do conclude that these barriers are key constituents in Europe’s present-day electrical vulnerability geography, and that the shaping of these constituents was historically situated and negotiated.

In addition, we would like to draw several broader conclusions. Firstly, our account suggests that the formal, political process of European Integration was mirrored, preceded even, by an electrical integration process organized by non-political actors representing the electric power sector. By the time the EU started to interfere in this domain, an impressive transnational power grid and associated governance structures had already been built. We see this process as a form of ‘hidden integration’ (Misa and Schot, 2005), that is, a European integration process hidden largely from public view, EU policy makers, and EU analysts. Like in so many other domains, this process was characterized by a particular mix of integration and fragmentation: Europe’s electrical geography carries a legacy from the 1950s and 1960s, during which time Europe was electrically interconnected, but borders remain visible between several meso-regions and between national or company systems.

Secondly, regarding the dynamics of electricity infrastructure development, many analysts routinely state the assumption of a more or less linear development sequence in which local systems developed into (micro)regional, national, and international systems. This paper, by contrast, observed how local, (micro)regional, national, (meso)regional and pan-European grid building were not simply successive developments, but – at least partly – simultaneous and mutually constitutive processes. This lesson from national electrification historiography (e.g. Van der Vleuten,
1998, 2010) applies equally to transnational electricity infrastructure dynamics. Thirdly and finally, while studying 4/11 we observed that the very perception of Europe’s electric power infrastructure and governance as ‘vulnerable’ or ‘reliable’ is contested, and that this contestation ties into current changes in the transnational governance landscape. In the wake of the large 2003 and 2006 blackouts, EU policy makers started to speak of a highly vulnerable electricity infrastructure in need of EU interference. The power sector’s international organizations, however, had recognized the issue of cascading failure in their early years and had taken measures accordingly. In their interpretation, these measures – and the decentralized model of transnational governance in which they were embodied – worked well during the Italian blackout of 2003 and on 4/11. The lights stayed on for the large majority of consumers, and the inconvenience for consumers who were shut off remained limited (to a maximum of 2 h on 4/11). Yet the EU problematizing of seemingly ‘weak’ sector governance seems to have gained the upper hand: Member States increasingly grant the EU powers in the electricity domain, using the vulnerability argument next to economic and sustainability arguments. The dynamics of these conflicting perceptions and changing transnational governance regimes merit further inquiry and explanation, and we shall return to this theme in a follow-up paper (Van der Vleuten and Lagendijk, 2009).

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