Twinning the Transitions?
The Missing Legal Frameworks of Digitalization and Decarbonization

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ABSTRACT

This paper adopts a Comparative Law and Economics perspective to argue that a real convergence between the digital and the low-carbon transitions is much harder to achieve than assumed so far. Drawing on examples from the EU and the USA, we point out that several convergence strategies are needed to ensure that potential synergies are fully exploited. Whether such strategies are implemented and what their contents should be largely depends on the possibility to adapt existing legal regimes. More specifically, I focus on the legal regime for electricity networks and the legal regime for digital technologies (AI systems, Internet of Things, cloud computing, digital twins) that could be deployed to support the decarbonization process. We discuss the interplay between decarbonization and digitalization with regard to different types of interventions: R&D subsidies to digitalize electricity networks; standard-setting strategies aimed at ensuring interoperability of digital technologies; regulatory incentives fostering the uptake of digital technologies in the energy sector; and regulatory incentives aimed at reducing GHG emissions connected to digital technologies. Additionally, we consider the management of data flows generated by the digitalization of the grids. From a methodological point of view, the twinning of the transitions is a useful example of a recurring theme in the Law and Economics literature: how to disentangle the complex causal relationships among economic, technological and legal drivers of institutional reforms.

1. *Introduction: looking for convergence strategies*

This paper adopts a Comparative Law and Economics perspective to argue that a real convergence between the digital and the low-carbon transitions is much harder to achieve than assumed so far. Drawing on examples from the EU and the USA, I point out that several convergence strategies are needed to ensure that potential synergies are fully exploited. Whether such strategies are implemented and what their contents should be largely depends on the possibility to adapt existing legal regimes. More specifically, I focus on the legal regime for electricity networks and the legal regime for digital technologies (AI systems, Internet of Things, cloud computing, digital twins) that could be deployed to support the decarbonization process. There is no doubt that the energy sector has already been deeply affected by the digitalization process, for example with reference to protection from cyberattacks, integration of increasing shares of renewable energy and implementation of energy efficiency policies. A specific focus on infrastructural choices allows a more in-depth exploration of the processes that shape the direction of technological and legal innovation. As pointed out by Künneke et al. (2021: 76-92), the physical components of the network, its governance and the services it makes possible shall be tightly coordinated and aligned with the institutional environment.

Most importantly, the digitalization of infrastructures represents the crucial step for the establishment of strong connections between the ICT and the energy sectors. How strong such connections should be, and what type of connections to foster, depends at least partly from the regulatory choices made in each legal system. At one extreme, the digital transition and the low-carbon transition can be made to depend on each other. At the other extreme, digitalization and decarbonization strategies can be assumed to be independent. That both extremes could sound plausible is the clearest signal of the ambivalence surrounding digitalization: it could be depicted as speeding up the transformation of energy systems or, alternatively, as the main factor that, by increasing the complexity of economic activities, contributed to the ‘Great Acceleration’ of GHG emissions ushering the Anthropocene (Creutzig et al., 2022: 484).

The EU has been more outspoken than the USA in linking the low-carbon and the digital transitions. In the European Green Deal communication (EC 2019d: 7), the digital transformation was identified as ‘a key enabler for reaching the Green Deal objectives’. Much emphasis on the twin ecological and digital transitions was also put in the Digital Europe communication (EC

2020…) and in the Digital Decade Policy Programme 2030 (Dec. 2022/2481). With the eruption of the pandemic crisis and the Russia-Ukraine crisis, the twin transitions became the main axes of the EU recovery plans. About two thirds of the total expenditures planned by MSs were bound to objectives in these two areas, thus largely exceeding the minimum targets set by Reg. 2021/241. The New Industrial Strategy (EC 2020…) and the Green Deal Industrial Plan for the Net-Zero Age (EC 2023…) both suggested that the competitiveness and strategic independence of the EU were directly related to the quality and quantity of the resources devoted to the twin transitions. The action plan for digitalizing energy (EC 2022…), represented the most sustained attempt at putting in place the coordination mechanisms which could foster the synergies while at the same time controlling for the collateral impacts of the two transitions. MSs were explicitly asked to promote an integrated approach to the twin transitions in their NECPs (EC, 2022…: 33) and in the REPowerEU chapters of the Recovery and Resilience Plans (EC, 2022…: 25f.). Digital and energy investment priorities also became the reference points in the external relationships with the main commercial partners (EC 2021…, 2022…).

The EU strategy is aligned with the views of international organizations on the role to be played by digitalization (e.g. IEA 2017, 2023). Conversely, the links between the two transitions are much less visible in the US federal policies. Of course, attention is paid to the large-scale implementation of digital technologies in the energy sector. However, the decarbonization benefits of such technologies are never foregrounded. National technological competitiveness and energy security are the objectives usually pursued. A twinning perspective only emerges in the US states that adopt more ambitious climate policies.

Several factors could determine whether twinning really happens and what its impact on decarbonization is. The digitalization of electricity networks can amount to no more than modular substitution (Geels &Turnheim, 2022: 31-3): new sensors and communications devices are added on top of the physical grid, but they do not significantly change the relationships between network operators and users. Or digitalization can prompt architectural reshaping, with a complete overhaul of technological complementarities and innovative solutions for network management. Whether incremental or radical innovations prevail is not only a matter of technological choices. The strategies pursued by innovators and incumbents matter as well (Mäkitie et al., 2023: 4). Furthermore, the dynamics of the digital and the energy sectors may significantly diverge. Innovation in the ICT sector is usually faster, but it does not automatically translate into an accelerated transition for the energy sector. The latter is much more dependent on infrastructures which adapt to radically new technologies with a significant time lag (Fouquet & Hippe 2022).

Other factors could reduce or slow down twinning opportunities. Digital markets have a strong tendency toward oligopolistic equilibria. A few tech giants, mostly from the USA and China, were able to control innovation processes and build up intellectual monopolies which leave no room for new entrants (Rikap & Lundvall 2021). Energy companies have to find ways to avoid a complete dependence from digital companies. No less relevant is the uncertainty about the real environmental benefits of digital technologies. Twinning should mean that the ICT sector is sustainable in itself and at the same time contributes to the decarbonization goals (Mäkitie et al., 2023: 4). As we shall see, both conditions require focused interventions.

We discuss the interplay between decarbonization and digitalization with regard to four types of interventions: R&D subsidies to digitalize electricity networks (Sec. 2); standard-setting strategies aimed at ensuring interoperability of digital technologies (Sec. 3); regulatory incentives fostering the uptake of digital technologies in the energy sector (Sec. 4); and regulatory incentives aimed at reducing GHG emissions connected to digital technologies (Sec. 5). The goal is to assess whether those measures prompted modular or architectural innovations and what the connections to the broader institutional contexts are. We then turn to the management of data flows generated by the digitalization of the grids (Sec. 6). Which data are shared and how not only affects the pace of digitalization, but also tilts the balance in favour of specific categories of stakeholders. In this case, too, the goal is to assess how the US and EU institutional contexts deal with the interplay between the ICT and energy sectors. From a methodological point of view, this is a useful example of a recurring theme in the Law and Economics literature: how to disentangle the complex causal relationships among economic, technological and legal drivers of institutional reforms. I return in sec. 7 to the lessons that the twin transitions can teach for this broader topic.

2. *Supporting smart grid technologies*

Starting in the 2000s, both the EU and the US funded broad research programs on smart and digital technologies. The multiplicity of additional functionalities associated with digital technologies allowed to present them as the best option to manage the trade-offs between sustainability, affordability and security of supply (Eid et al. 2017). At the inception of the digitalization process, the clusters of technologies grouped under the smart grid label were the main catalyst. Beneath a superficial convergence, the EU and US strategies did not pursue the same goals. Differences already emerged when the first legislative definitions of smart grids were introduced.

The EISAct07 devoted Title XIII to the smart grid. Sect. 1301 listed ten different aspects of smart grids, ranging from increased use of digital information and controls technology to integration of DERs to deployment and integration of advanced electricity storage and peak-shaving technologies. Sec. 1305 mandated NIST to develop an interoperability framework for smart grid devices and systems. Sec. 1307 asked states to consider rate recovery to support utilities investing in smart grid systems. ARRA09 kept the previous definition of smart grid, but significantly boosted investments related to clean technologies. Federal funding for grid modernization, administered through ARPA-E, amounted to more than $4 billion, and was matched by private investments for an equivalent amount. The main outcomes related to the deployment of units for real-time measurement of grid metrics and of smart meters, as well as the automation of distribution network management functions (DOE 2016d; Executive Office US President 2016). In the following years, federal funds were allocated both through ARPA-E programs (DOE 2022d) and the Grid Modernization initiative, launched in 2015 (DOE 2020). Sec. 40107 IIJ Act re-introduced the Smart Grids Grants, with additional eligible investment areas and funding of up to $3 billion until 2026. No changes were made to the definition of smart grid. The Chips and Science Act of 2022, spurring the largest R&D publicly funded program in American history, allocated funds to DOE for research on advanced computing and quantum network infrastructure (sec. 10104), as well as on microelectronics for energy applications (sec. 10731).

The EU waited until 2013 before adopting a legislative definition of smart grid (Article 2(7) Reg. 2013/347). It was later replaced with two broader definitions, one for smart electricity grids (Article 2(9) Reg. 2022/869) and one for smart gas grids (Article 2(10) Reg. 2022/869). Though, EU strategies on smart grids already started in the 2000 and were initially focused on two goals: on one hand, to coordinate research efforts; on the other hand, to promote those technologies which supported the liberalization process. As to research efforts, smart grids were already addressed by one of the Energy Technology Platforms established in 2005 and aimed at developing common visions within the energy industry (ETP Smart Grids 2006; 2007). The adoption of the SET Plan (EC 2007…) signaled the attempt to shift to the EU level the power to select technological priorities (Eikeland & Skjærseth 2020). The number of bodies involved in the coordination of EU energy research increased, but smart grids were always included among the research priorities. The SET Plan underwent further revisions when energy research became the fifth pillar of the Energy Union framework (EC 2015a). On the industry side, tasks related to promoting innovation in electricity grids are managed by ETIP SNET, successor to the Energy Technology Platform on Smart Grids (ETIP SNET 2017). A crucial role is played by ENTSO-E, which publishes its own research targets and strategy according to Article 30(1)(i) Reg. 2019/943 (ENTSO-E 2020…). The Implementation

Working Group on Energy Systems coordinates MSs activities related to the adoption of innovative solutions for RES integration, systems integration and flexibility (IWG4 Implementation Plan 2021). It receives inputs from ETIP SNET and the Joint Programming Platform Smart Energy Systems, the latter being focused on fostering connections across the whole innovation chain. On the academic side, the European Energy Research Alliance, also established by the SET Plan, started a Joint Programme on Smart Grids in 2010 and from 2021 relied on the transversal Joint Programme Digitalization for Energy to coordinate cross-cutting research from the energy and digitalization sectors (EERA 2021). In the revamped SET Plan (EC 2023…), more attention was paid to the relevance of digitalization as a cross-cutting issue in all the IWGs.

The link between the liberalization process and smart grids was most visible in the adoption of legislative definitions for smart metering systems, first in Article 2(28) Dir. 2012/27, then in Article 2(23) Dir. 2019/944. By introducing these definitions, the EU was able to adopt a mandatory target of 80 per cent of smart meters by 2020 (Annex I(2) Dir. 2009/72). The target could be conditional upon a positive cost-benefit assessment in each MS. Several MSs missed the target, so Annex II(3) Dir. 2019/944 moved the deadline to 2024. A broader and more systemic view transpires from Articles 30(1)(h) and 55(1)(d) Reg. 2019/943, asking ENTSO-E and the DSO Entity to promote the digitalization of networks, including the deployment of smart grids, efficient real time data acquisition and intelligent metering systems. The Commission also relied on a networking strategy by setting up in 2009 the Smart Grids Task Force (SGTF), in charge of drafting recommendations on the regulatory revisions required by the implementation of smart grid technologies. The activity of the SGTF proved instrumental in brokering agreements among national energy regulators, standardization organizations, data protection authorities, energy and ICT market operators, consumer organizations and MSs on regulatory issues. Since 2022, the SGTF is co-chaired by DG ENER and DGCNET. Its tasks are mainly related to the implementation of the Digitalization of the Energy Sector Action Plan.

The evolving definitions in the USA and the EU confirm the observations repeatedly made from several disciplinary angles: smart grids, and digitalization strategies more generally, play the role of empowering specific categories of decision-makers, selecting specific technologies and providing specific kinds of benefits. Implementation problems, and the deeper transformations they entail, are often downplayed, despite a general awareness that digital technologies rarely work as expected (Stephens et al. 2015; Beaulieu 2016; Lovell 2022). The US and EU strategies started from opposite perspectives: the former was more interested in enhancing the reliability of the centralized grids; the latter was more interested in exploring decentralized solutions (Coll-Mayor et al. 2007). Over time, this contrast became less useful to describe the respective technological trajectories. The two blocks explicitly sought to foster a high degree of convergence on smart grids, both bilaterally (e.g. through the EU-US Energy Council: see Giordano & Bossart 2012) and through international networks. Several such networks have been established to promote grid-related technologies. They differ from the point of view of the geographical remit and the focus on a specific phase of the innovation chain. The International Smart Grid Action Network (ISGAN) was established in 2010 by the Clean Energy Ministerial (CEM), an intergovernmental network launched by the United States and then joined by China, the European Commission and other countries (Tosun & Rinscheid 2021). From 2011, ISGAN operates within the framework of the IEA Technology Cooperation Programmes. It supports the identification of R&I priorities for smart grid technologies, analysis of their implementation, laboratory testing, cost-benefit assessment, collection of data on regulatory innovations and knowledge transfer initiatives (ETIP SNET 2019). Mission Innovation is another intergovernmental network launched at COP21 in Paris and joined by the USA, the EU, China and other countries representing over 90 per cent of global clean energy investments. It supports public-private partnerships engaged in the demonstration and development of smart grids technologies. In its first phase, the innovation challenge on smart grids focused on a variety of grid applications. From 2021, the Green Powered Future Mission aimed at accelerating the digitalization of the energy sector. The Global Smart Energy Federation, established in 2012, coordinates the activities of national and regional associations, utilities and research centres in Africa, America, Asia and Europe. The GO15, established in 2004 and progressively expanded, reunites very large TSOs from Europe, The USA, South America, Africa and Asia, with the aim of favouring international collaboration and preparing a sustainable future.

Vying for leadership in these networks can be driven by the desire to export technological solutions or regulatory innovations. Investing in these networks can also strengthen domestic policies. Benefits from participation are usually related to knowledge sharing and the pursuit of common strategies in several international fora. It is more difficult to find direct evidence that these networks do have a significant impact of the speed of digitalization or the convergence toward common visions. It is often the case that the proposed approaches reflect national or regional priorities, thus leaving little space for alternative views (Tosun & Rinscheid 2023; Tosun et al. 2023). Even more doubtful is whether these networks support technology transfer to developing countries.

Notwithstanding, two reasons explain why the interplay of national, regional and international digitalization strategies shall be highlighted.

The first reason has to do with the features of the first and second wave of grid-related technological innovations. The first wave was mainly related to improvements in traditional tasks of network management. The second wave started to produce deeper changes in the relationships among network operators, users, and ITC suppliers. This means that a variety of outcomes is possible, depending on the structure of the energy and ICT industries, as well as on how their relationships are regulated. Consider the following two examples of cutting-edge technologies, promising to change how electricity networks are managed.

The first example concerns Internet of Things (IoT) technologies. They provide the solutions to manage the huge amount of data generated by the sensors installed on smart grids or users' premises. The main components of IoT are: a data collection layer, which relies on sensors to detect variations of relevant factors, and actuators to convert signals in an automated action; a communication layer, which manages both the communication among the local devices and the transfer of data to a remote platform for further processing; and a data processing layer, which relies on cloud computing (centralized processing) or fog and edge computing (decentralized processing closer to users) to provide the analysis required for decision-making tasks (Motlagh et al. 2020; Abir et al. 2021). In each layer, several technologies are available for the different functions. This means that interfaces among the layers shall be capable of receiving different types of messages and connect different types of devices. In its most advanced configurations, an IoT-based electricity network resembles the information internet from the point of view of the interlinkages among a large number of devices. At the same time, this 'energy internet' differs from the information internet because it needs to simultaneously consider bidirectional flows of energy, data, and money (Joseph & Balachandra 2020). The biggest transformation has to do with the shift from the traditional preeminence of physical infrastructures toward the dominance of the layers for data collection, communication and processing. In IoT systems, traditional network operators can still play a central role, but only if they embrace business models that integrate innovative services (Muhanji et al. 2019; Wu et al. 2021).

The second example concerns the AI systems which enhance the accuracy of predictions about network management. Several algorithms have been tested for problems like generation and demand forecasting, detection of fault in power lines, predicting grid stability, supporting energy saving, reducing emissions from fossil fuels, planning sustainable infrastructures, and reducing power losses. Benefits are already visible, but the computational complexity of predictive models and the accuracy of energy data from a multiplicity of sources are difficult to handle (Donti & Kolter 2021; Ahmad et al. 2021; Rangel-Martinez et al. 2021; Szczepaniuk & Szczepaniuk 2023).

Also, the performance and benefits of AI systems directly depend on the availability of data collected through the IoT infrastructure. This means that an almost perfect integration of the two systems is needed. For example, a digital twin is a virtual representation of a physical object (e.g. the electricity network) which can be relied upon to carry out simulation and support decision-making activities. It is envisioned as the next evolutionary step from traditional control technologies to a broader set of dynamic forecasting capabilities (Sifat et al. 2023). If digital twins, and AI systems more generally, become the main decision-making tool, it can be expected that all groups of interested stakeholders need to agree on how to use them. Network operators should coordinate with regulators, generators, other network users, and operators of digital infrastructures. Such coordination entails significant organizational changes with large costs. Data from different domains should be shared in real time. Furthermore, a common understanding of the risks stemming from the inaccuracy of data processing is required. Network operators might not trust AI systems because they do not understand the reasons for an algorithm making a specific prediction, or more generally how AI systems work. Regulators, too, need to understand whether security standards are complied with, what the impact on AI systems on competition is and why a specific AI algorithm was chosen. Some progress is being made with explainable AI techniques, whose goal is to make the process behind the prediction output more transparent. Which criteria to adopt for the explanation and how to address trade-offs between too much transparency and too much confidence in AI systems is still unclear (Machlev et al. 2022; Xu et al. 2022). An additional issue is how to ensure that AI systems comply with energy justice principles, for example from the point of view of the fair distribution of costs among final users, the accountability of AI systems and the consideration of all relevant stakeholders (Noorman et al. 2023). Should coordination about shared standards, data exchange protocols and risk assessments not be feasible, energy companies could discard or slow down the adoption of AI systems, no matter how large their future benefits could be.

The second reason why the interplay of national, regional and international strategies is highly relevant has to do with the global competition for digital technologies. It has been pointed out that widespread reliance on AI systems changes the very nature of the innovation process: only companies controlling access to large data sets are able to improve the accuracy of their algorithms. Thanks to this initial advantage, these companies can establish a particularly dangerous version of intellectual monopoly. The best-performing algorithms can quickly identify the most promising combinations of existing knowledge. If control of data sets is merged with a high number of intellectual property rights on crucial AI technologies, as well as control of cloud infrastructures and digital platforms, new entrants will struggle to challenge the concentration of economic power in the hands of intellectual monopolists (Rikap & Lundvall, 2021: 35).

A poignant example of an intellectual monopoly in the energy sector is represented by State Grid Corporation of China (Xu 2016; Andrews-Speed & Zhang, 2019: 140-2, 150-3; Rikap 2022). With strong support from the Chinese government, State Grid moved from being a small energy company in the early 2000s to establishing itself as the biggest utility in the world and the owner of a large patent portfolio for digital technologies. This achievement was largely due to a national innovation policy which pursued the goal of modernizing the Chinese energy sector. State Grid was given the exclusive power to decide investment priorities and exploit the benefits of research undertaken in Chinese universities. The Chinese leadership on technologies for Ultra-High-Voltage electricity transmission networks is the most visible accomplishment, but no less relevant was the investment made on microgrids and distribution grids (He et al. 2020). From mid-2010s, Chinese strategic documents on innovation policies regularly include the digitalization of the energy sector among the top priorities (Sandalow et al., 2022: 187-91). Thanks to the support it received at home, State Grid started to export its technologies and gained more influence in the international standardization bodies. China adopted much the same strategy for the standardization of AI systems more generally (Cantero Gamito 2021). Both the EU and the US digital strategies are clearly aware of, and tried to avoid, the risk of a new technological dependence. Apart from geopolitical issues, the most worrisome aspect is that the Chinese example confirms the general trend of economic power concentration prompted by digital technologies. If a few ICT companies control the technologies needed for the digitalization of the energy sector, the whole innovation process might be skewed toward objectives which reduce benefits for a large number of users and society at large. In theory, the international networks mentioned above could negotiate global standards which ensure the environmental sustainability of the digitalization process. In practice, those networks are unlikely to overcome the technological rivalry among the EU, the USA and China.

3. *Searching for interoperability*

Interoperability of technologies takes on several meanings. During the twentieth century, the key transformation has been the shift from mechanical interactions among physical components of industrial equipment to virtual interactions reliant upon wired and wireless communication infrastructures. The content of such virtual interactions is represented by data that can be used to perform specific tasks within the system. With an increasing number of devices connected to, or interacting with, the electricity networks, interoperability issues become the main concern for the effective management of complex systems. Two such issues shall be highlighted.

The first has to do with the interplay between the legacy infrastructures and the new digital technologies. Whereas the traditional electricity networks relied upon analogical technologies which ensured stability even in case of deviations from ideal conditions, the new physics of power electronics require a much more careful evaluation of network stability conditions (NIST, 2021: 34-8). Given that the electricity infrastructures cannot be changed overnight, the interplay between legacy and new technologies is not only relevant for the early phase of the transition from the analogical to the digital world, but also for the next waves of new digital technologies.

The second interoperability issue has to do with the increasing number of connections to domains external to the electricity sector. Sector coupling requires to jointly manage several energy and transport infrastructures. The electricity networks shall also communicate with the buildings sector, the industry sector and the logistics sector. Furthermore, these connections change over time as new technologies become available and new commercial relationships are established. The variety of cross-domain interactions clearly shows that, without interoperability, the benefits of digitalization cannot be obtained.

The complexity just summarized already delimits the scope of interoperability. The final outcome of the digitalization process cannot be the adoption of universal models which allow interactions among all devices and infrastructures. Agreements on such universal models would be too cumbersome to reach and update. Nor can it be assumed that each new device entering the market shall be made compatible with all existing devices. In this case, too, the costs of adapting each device would be too high. The only feasible option is to identify shared interfaces which reduce the ‘distance’ between digital components and ensure interoperability without requiring complete uniformity in the technical features of each device (IEC, 2019: 83-7).

From this point of view, a distinction can be made between technical and informational interoperability (Schütz et al. 2021). The former includes the basic connectivity establishing physical and logical connections among infrastructure components, network interoperability with standardized formats for exchanging messages among systems, and syntactic interoperability with communication protocols which allow to share an understanding of message data structures. The latter includes semantic understanding, with a shared information model allowing to interpret information, and a shared understanding of the business context. Both types of interoperability are required to reduce the costs of integrating different technologies. A representation of the interactions among grid components and the related interoperability needs is provided by the Smart

Grid Architecture Model (SGAM), first proposed in the USA by the GridWise Architecture Council and then adopted by international and European standardization organizations (CEN/CENELEC/ETSI 2012, 2014; IEC 2017, 2021; Gottschalk et al. 2017; Uslar et al. 2019; Schütz et al. 2021). The SGAM links technical interoperability to the component layer, where the physical components of the electricity network are located, and to the communication layer, where communication protocols are implemented. Informational interoperability is linked to the information layer, where common data models allow to specify the requirements for the business functions. For both types of interoperability, standards have to be adopted to connect the different layers. For example, standards are needed both to ensure that DSO or metering operators can collect energy consumption data from individual consumers' meters (technical interoperability) and to ensure the same data can be communicated in a readable format to the consumers themselves or to authorized third parties (information interoperability).

Despite its huge benefits, interoperability is not always available at the right time and for all types of technologies. The degree of interoperability depends on the dynamics of cooperation and competition between technology providers and users. In many cases, interoperability standards are supported by the industry because they create and expand markets for digital technologies. Though, the lack of interoperability can strengthen market power. The adoption of standards might be hindered because of a divergence between private and social benefits. Furthermore, interoperability standards could reduce innovation if the uniformity they impose prevents the emergence of other technologies. Hence, strategies to support interoperability are needed. In the energy sector, both the USA and the EU implemented such strategies. Though, both their contents and the results they achieved were influenced by the organization of their standardization systems.

The US standardization system is strongly decentered and relies on private standard-setting organizations. Conversely, the EU standardization system is more centralized: it relies on standardization mandates issued to the European standard-setting organizations. The legal value of the standards also differs in the two systems: in the US, industry standards can be incorporated by reference in the federal legislation; in the EU, compliance with the standards issued by the European standard-setting organizations (so called harmonized standards) automatically entrusts users to trade goods and services within the EU. This means that US standards are voluntary unless incorporated into US laws, while EU harmonized standards are formally voluntary but de facto binding (Büthe & Mattli 2011; Bremer 2016). To be sure, EU and international standards can also become binding because they are referred to or incorporated into EU and national legislation. In this case, there is a convergence of the EU and US standardization systems.

The US and EU interoperability strategies can be compared along two dimensions: first, how did the two legal systems ensure the coordination among standard-setting bodies and promote the adoption of interoperability standards? Second, how did the two legal systems manage the frictions between the protection of intellectual property rights and interoperability?

As far as coordination is concerned, the main barrier is represented by the lack of stable relationships between the energy and the ICT sectors. Starting from the 2000s, the first wave of digital technologies already made clear that new cross-sector arrangements were needed between energy and ICT companies. Divergent approaches to the way new technologies were tested and adopted in the two sectors hampered, or delayed, the approval of standards related to the digital technologies for the electricity networks. With the later waves of digital technologies, and in particular with the diffusion of IoT approaches, coordination became even more difficult. The ICT sector itself suffers from a lack of coordination, if not hyper-fragmentation (Hodapp & Hanelt 2022). Hence, attempts to standardize the solutions for the energy sector required additional efforts. The USA and the EU chose two different strategies: in the former, the federal government tried to steer coordination, but did not significantly alter the traditional organization of the US standardization system; in the latter, a broader and more prescriptive set of tools was gradually adopted thanks to the link between the liberalization policies and the implementation of smart grid technologies.

Sec. 1305 EISAct07 charged the NIST with the task of coordinating the development of a framework to achieve the interoperability of smart grid devices and systems. Once interoperability standards led to a sufficient consensus, the FERC should consider their adoption. This provision clearly mirrored the procedure already in place for cybersecurity standards. Though, the approach envisaged by the EISAct07 only worked partially. In 2009, the NIST established the Smart Grid Interoperability Panel (SGIP) as a public-private partnership in charge of reviewing and recommending the standards developed by standard-setting bodies. From 2013, the SGIP became a private non profit organization. In 2017, it merged with the Smart Electric Power Alliance (SEPA), a non profit organization with membership in the utilities sector, the state PUCs and big US corporations. The catalog of interoperability standards these two organizations were able to assemble are the most successful aspect of the US strategy. Another useful contribution to interoperability was NIST’s smart grid framework, first published in 2010 and then updated three times until 2021. This document provided a conceptual model of the smart grid and highlighted the main interactions to consider (Ho & O’Sullivan 2019). Less successful was the attempt to support the widespread adoption of these standards. The FERC (2009) issued a policy statement to highlight the urgency of a significant investment in smart grid technologies. However, two years later (FERC 2011), it declined to endorse the standards recommended by the SGIP. The reason was that no widespread consensus had been achieved. Such decision could be read as the signal of strong opposition to a broader role of the federal government in the standardization process. No less relevant is the jurisdictional divide, with the states refusing to delegate to the federal level the choices directly connected to the modernization of the grids. According to Eisen (2013: 44-55), the FERC wisely administrated energy federalism. The possibility for an intervention at a later stage was left open. For example, mandatory standards could be useful if too divergent standards are adopted at state level, a few strong players control the standardization process, or compliance with cybersecurity safeguards needs to be ensured. Outside these cases, the process coordinated by the NIST was expected to be better suited than traditional federal rulemaking to promote the adoption of hundreds of smart grid standards over the years. By the early 2020s, these expectations were only partially fulfilled. Initiatives to support interoperability at distribution systems level have been ad hoc and informal. Information made available at national level is difficult to use at state level and requires additional efforts by PUCs to be translated into useful guidance for local utilities (ICF 2016). More generally, we shall see below that states' approaches to grid modernization are far from converging. Additionally, the NIST (2021: 93f.) highlighted that only a small percentage of the existing interoperability standards could undergo the testing and certification process. Without such a process, there is no possibility to reduce uncertainty about the real costs of integrating digital solutions into the grid. In the late 2010s, DOE (2018…) was still striving to devise a broad interoperability strategy, thus signaling that industry-driven coordination was facing hurdles.

The European Commission initially relied on two tools: the standardization mandate and the legislative requirements on the interoperability of smart meters. As to the former, the Smart Grid mandate (EC 2011) asked the European standard-setting bodies to develop a framework enabling continuous standard enhancement and development in the field of smart grids. More specific standardization mandates were issued for utility meters (EC 2009) and EV charging (2010…). These mandates prompted the establishment of a permanent CEN-CENELEC-ETSI coordination group on smart grids. Its work is aligned with the selection of standards taking place at international level within the IEC (see e.g. the smart grid standardization roadmap in IEC 2017). As to the latter, interoperability was mentioned, together with EU and international standards and best practices, among the criteria each MS had to consider in its plan for rolling out smart meters (Annex I.2 Dir. 2019/72; Rec. 2012/148). The meaning of interoperability was a narrow one: it was only meant to ensure that competition among suppliers in retail markets was not hampered. Neither tool promoted continental-wide convergence toward shared interoperability standards. A significant degree of progress on information interoperability could only be observed for transmission network data, mainly because of the direct involvement of ENTSO-E in the standardization process and its role in the implementation of EU network codes (ENTSO-E 2019…, 2020…). Conversely, little progress on interoperability was made for data exchanges related to retail markets business processes. MSs chose different paths toward standardization in this domain: data formats and types, description of the business processes, possible exceptions related to public service obligations were all tailored to national needs. Across MSs, interoperability of data exchanges was seriously limited. Furthermore, standardization at national level was mainly concerned with the technical dimension of interoperability, much less with the information dimension (Küpper et al. 2018).

In order to foster a higher degree of interoperability, both within and across MSs, the Commission tried to move to the EU level the task of providing harmonized data formats in the electricity sector. The co-legislators rejected this approach in favour of a milder version of harmonization: the Commission was entrusted with the adoption of implementing acts on interoperability requirements and procedures for access to energy services data. Such requirements and procedures have to be based on existing national practices, thus confirming that only partial harmonization is possible (Article 24 Dir. 2019/944). The same approach was later replicated in the gas and hydrogen sector (Articles 17 and 22 Dir. Gas/hydrogen). Reg. 2023/1162 was the first implementing act for the electricity sector, with regard to metering and consumption data. It clarified that the harmonization of interoperability requirements would take place through an EU reference model setting out common rules and procedures for the business, function and information layers (SGTF 2022). In the SGAM, these layers are related to information interoperability. The communication and component layers, related to technical interoperability, are left to MSs' choices. The EU reference model does not prevent MSs from adopting divergent national practices. Though, they are required to report about the implementation of the reference model. National practices are collected in a publicly available repository to be managed by ENTSO-E and the DSO Entity. These two bodies shall also advise the Commission about future revisions to the reference model. The EU also funded the establishment of the Interoperability Network for the Energy Transition, with the goal of providing horizontal coordination and support to the European interoperability ecosystem. However gradual this approach can be, it is a big step forward to develop cross-border data exchanges and multiply the solutions for data governance. While the early interventions embraced a narrow meaning of interoperability and only focused on the technical aspects of devices, the new approach considers the systemic aspects of interoperability in all architectural layers and for all energy services (Reif & Meeus 2022). We shall see in Sec. 9.3.2 that the adoption of reference models is a key enabler of the EU energy data space.

Over time, the partial harmonization solution adopted in the electricity sector could give way to more ambitious solutions. The recast Directive on the energy performance of buildings includes provisions (Article 14) requiring MSs to mandate the adoption of international standards for the exchange of building systems data. The Commission's implementing acts could lead to full harmonization. Similarly, the Regulation on the deployment of alternative fuels infrastructure delegates the Commission to adopt technical specifications to enable automated and uniform data exchanges between operators of publicly accessible recharging points and data users (Article 20). In this case, too, full harmonization is envisaged. The same trend can be observed in the proposal for an Interoperable Europe Act (EC 2022…). In order to foster interoperability in the public sector, the proposal transforms the non-binding guidelines of the European Interoperability Framework (EIF) (EC 2017) into a single reference point for all national public administrations. The EIF covers all dimensions of interoperability, thus suggesting that it could pave the way for further harmonization in all sectors, including the energy one. More generally, the introduction of alternative routes to the standardization of interoperability solutions reflects the broader changes in the EU standardization system. In order to fulfil the EU policy goals, the Commission is subjecting EU standard-setting activities to heightened scrutiny. Whether this approach fosters innovation and increases the influence of EU standards at global level remains to be seen (Baron & Larouche 2023).

Turning now to intellectual property rights, a major implication of the digitalization process is that thousands of patents related to IoT and AI technologies become relevant to the energy sector. The interoperability standards require energy companies implementing them to license those patents. A standard essential patent (SEP) is usually defined as a patent covering a technology whose use is required by the implementation of a standard (e.g. IEC/ISO/ITU 2022). For several decades, the ICT sector has struggled with the issues related to the negotiation of SEP licenses. Four such issues proved to be the most controversial ones:

1) SEP holders might hold up standard implementers by asking unreasonably high royalties.
2) SEP holders might engage in so called royalty stacking, that is force standard implementers to pay royalties for hundreds or thousands of patents, so that the total amount of the royalties becomes excessive in the aggregate.
3) SEP holders might engage in so called patent ambush, that is fail to disclose patents to standard-setting organizations (SSOs) and enforcing them against standard implementers at a later stage.

4) Standard implementers might hold out SEP holders by refusing to pay the royalties or forcing them to accept lower royalties.

Widely divergent views have been expressed about the systemic impact of these four strategies on the ICT industry. Strong disagreements can also be observed about the need for patent law reform, the role of competition law and the possibility for self-regulation through SSOs. The digitalization of the energy sector introduces an additional problem: how licenses should be negotiated when the number of potential standards implementers becomes much larger and heterogeneous. Adopting IoT technologies means that each product will need to comply with multiple standards, each standard will include multiple SEPs, and each standard could be implemented in different products in different industries (Baron et al., 2023: 15-24). The risk of a high rate of litigation because of a lack of agreement on the conditions for licensing digital technologies to energy companies was already pointed out during the first wave of smart grid innovations (Contreras 2012). Hopes that the standardization process could reduce frictions by requiring from SEP holders a commitment to fair, reasonable and non-discriminatory (FRAND) license terms went unfulfilled. Even when commitments are made, they do not significantly reduce the risks related to the four types of strategic behavior described above. With the digitalization of the energy sector in full swing, cross-industry licensing becomes crucial to ensure interoperability. Yet, fundamental questions still wait for an answer. Perhaps the most pressing one is the kind of engagement to be expected between SEP holders and standard implementers in the energy sector. Within the ICT sector, the prevailing commercial strategy has been to negotiate licenses with the lowest levels of the supply chain, i.e. the manufacturers of end products. Conversely, SEP holders refuse to negotiate licenses with suppliers of components in the upstream segments of the supply chains (Storm 2022). An example of such a strategy in the energy sector could be to only license downstream manufacturers of smart meters or sensors while refusing to license upstream suppliers of components (e.g. wireless transmission technologies) for those end products. The advantages for SEP holders are twofold: first, higher royalties, related to the market price of the end product, can usually be obtained from downstream manufacturers than from suppliers of components; second, licensing the downstream players avoids the application of the patent exhaustion doctrine, which would prevent the enforcement of patents after a product incorporating the patented technology is sold to suppliers of components.

Whatever the soundness of this strategy in the ICT sector, it raises several concerns when cross-industry licensing is involved. To begin with, end products manufacturers in the energy sector might be unfamiliar with the technologies embedded in complex products they buy. Negotiating about royalties with SEP holders could be more difficult for them than for upstream suppliers of components (Geradin & Katsifis 2021). If licenses with many SEP holders have to be negotiated, the problem of royalty stacking could become serious (Henkel 2022). Uncertainty about licensing could also reduce downstream companies' incentives to innovate (Henkel 2022). Second, the large number of end products manufacturers could significantly increase the transaction costs of negotiating downstream licenses. Trends in IoT markets suggest that the upstream segment of component suppliers should be less fragmented, hence involving lower transaction costs for upstream SEP licensing (Henkel 2022). Third, it is unclear whether licensing downstream is the only way for SEP holders to receive a fair remuneration for their patented technologies. Upstream licensing could be structured to make a fair remuneration possible. The added value of each patent could be identified without complex distinctions among the multiple components embedded in the end product (Henkel 2022). Also, upstream licensing prevents litigation motivated by suspicions that downstream licensing is an attempt to hold up standard implementers. Price discrimination, which takes into account the added value for each use of the technology, could be deemed valid at upstream level, provided it is related to objective factors, for example the performance rates for different applications (Henkel 2022). Fourth, and more generally, the digitalization of the energy sector is linked to energy security goals, industry competitiveness goals, and environmental goals. At least in the EU, the need to simultaneously move forward with the digital and ecological transitions was explicitly stated. This means that, whatever the benefits for SEP holders and technological innovation more generally, the strategy of downstream licensing can only be deemed acceptable if it does not hamper the twin transitions. Given the widely divergent views about the risk of hold up damaging standard implementers and the risk of hold out damaging SEP holders, the preferable course of action is to devise a legal regime for SEP licensing which provides a fair remuneration to SEP holders independently from the supply chain level where licenses are negotiated (Heiden et al. 2021; SEPs Expert Group, 2021: 84f.; Geradin 2021).

How can the US and EU regulatory systems ensure that SEP licensing does not hamper interoperability and the digitalization process? Again, the answer lies in the structure of their standardization systems. In the USA, the industry practice of licensing downstream was held not to violate US antitrust law in two high-profile federal cases, one in the cellular chip market (*FTC v. Qualcomm*) and one in the automotive sector (*Continental v. Avanci*). Federal authorities adopted contrasting positions. During the Trump administration, the USPTO, DOJ and NIST (2019) issued a policy statement to support good faith negotiation of SEP licenses while at the same time underlining that all remedies against infringers should be available. No role was envisaged for antitrust law. During the Biden administration, the statement was withdrawn (USPTO et al. 2022), but the crucial role of FRAND commitments in SSOs was acknowledged. At the same time, the possibility to review both SEP holders and standard implementers practices according to antitrust law was explicitly mentioned. The FTC did not join either document, clearly signaling its intention to pursue its own enforcement strategy in the field of SEP licensing. Though, FTC commissioners disagree about the best means to balance the opposite risks of hold up and hold out (e.g. Khan & Slaughter 2022; Wilson 2022). These internal divisions could prevent the FTC from playing a key role in SEP disputes. At least in theory, broader regulatory measures are available in US law and could be implemented in the energy sector: march-in rights according to the Bayh-Dole Act of 1980, enabling the federal government to mandate licensing on reasonable terms when federal funding is provided for energy technologies; reasonable compensation to SEP holders for government use of NIST-recommended standards; statutory compulsory licensing; a prohibition on injunctive relief for SEP standards related to the digitalization of the energy sector; or a mandatory patent pool (Contreras, 2012: 671-5). None of these more interventionist solutions is being widely debated, thus confirming that interoperability issues shall be addressed within the boundaries of the decentralized US standardization system.

For a long time, the EU followed the same path as the USA. Issues related to SEP licensing were left to SSOs' patent policies and to national and EU litigation (Barazza 2023). The landmark ECJ judgment in *Huawei v. ZTE* established a framework for good faith negotiation of SEP licenses, but did not stop litigation. National courts kept refining the respective obligations of SEP holders and standard implementers. German courts decided most cases in Europe. They took side with SEP holders by accepting that the latter can choose the licensing level (von Brasch 2023). In the UK, the Supreme Court held that SEP holders can apply different royalty rates to different licensees, but those rates should reflect the true value of the patent and not depend on individual or idiosyncratic characteristics of the licensee (*Unwired v. Huawei*, par. 114, 122). This statement seems to suggest that the licensing level should not change FRAND assessments.

In 2023, the proposal for a Regulation on SEP marked a turning point and widened the distance between the EU and US approaches. The proposal aims at providing a balanced solution to both the hold up and hold out risks. It would put in place four main interventions: first, transparency is increased through the establishment of an obligatory register, held by EUIPO, that will provide information about SEPs in Europe, FRAND terms and conditions, licensing programs; second, selected SEP will be subject to a non-binding essentiality check; third, aggregated maximum royalty rates can be notified in the register by SEP holders or identified through a non-binding recommendation by a conciliator; third, an out-of-court dispute resolution mechanism for FRAND determination must be tried by the parties before they resort to litigation.

With specific regard to the choice of the licensing level, the proposed Regulation clearly suggests that it is one of the factors to be taken into account. To begin with, transparency of licensing conditions is addressed from the point of view of the whole chain (rec. 2). Secondly, the expert opinion of the EUIPO competence centre on the aggregate royalty shall consider the expected impact on SEP holders and stakeholders in the value chain, customary rules and practices for licensing in the value chain, and impact on incentives to innovate of SEP holders and different stakeholders (rec. 16 and Article 18(12) proposed SEP Reg.). Thirdly, the competence centre shall reduce frictions along the value chain by raising awareness of SEP licensing (rec. 45 and Article 3(2)(j) proposed SEP Reg.). Fourth, when submitting suggestions for FRAND terms and conditions, the conciliator shall take into account the impact on the value chain (Article 50(3) proposed SEP Reg.).

The Commission chose to adopt procedural provisions which do not determine uniform solutions for all SEPs and all industries. As discussed above, several factors influence the licensing strategies. The proposal is meant to reduce both transaction costs and litigation costs. According to some commentators, this goal cannot be achieved because the proposed procedures do not reduce the distance between SEP holders and implementers and do not lead to royalties which foster innovation (Nikolic 2023; Baron 2023). Though, the argument can be made that the increased transparency brought by the proposed Regulation should make it easier to identify instances of hold up or hold out. The guidance issued by the Commission (Article 69 proposed SEP Reg.) could also be used to define reference points on the legality of different licensing strategies in each industry.

In the impact assessment supporting the proposed Regulation, the Commission (EC, 2023…: 68, 70) reported information collected by SME manufacturers in the energy sector. They confirmed that innovative solutions for smart meters, smart home appliances and EV charging required negotiating a license for WiFi or 4G connectivity. SEP licensing is also considered of crucial relevance for the integration of edge computing into smart electricity grids (EC, 2023…: 134). SEP holders refuse to license components suppliers, thus leading to tensions about the indemnification for royalties due to the end product manufacturers. When licenses are too costly, technologically inferior solutions are chosen. In the energy sector, sales often happen through public tendering procedures and interoperability is mandated by EU law. If manufacturers have to pay royalties, passing down this additional cost to public undertakings could be difficult (EC, 2023…: 143). Much the same arguments were voiced by industry associations, which called for licensing at all levels on terms which only reflect the value of the component implementing the SEPs (ESMIG 2021). This information does not provide conclusive evidence on the systemic impact of hold up, hold up or royalty stacking. However, it does suggest that there is room for a regulatory regime complementing the EU standardization system.

Comparing the US and EU interoperability strategies shows that, to a significant extent, both rely on a mix of private and public governance. Where the main difference lies is in the availability of solutions which can foster interoperability when the standardization system does not prove adequate. The US system reacts to the limits of the standardization system by providing additional support to private governance mechanisms. A significant overhaul of the existing structures, or broader public involvement, is deemed not to be justified. The patent system, too, is generally perceived to be conducive to efficient negotiations between patent holders and licensees, even though high litigation rates raise doubts about such a view. The EU system has progressively reduced its exclusive reliance on SSOs and introduced alternative legal tools to foster interoperability. This widening divergence can be explained by entrenched visions about the role of intellectual property law: in the USA, the latter is deemed the best legal tool to promote innovation; in the EU, other legal tools can sometimes correct its failures (Maggiolino & Zoboli 2021). It can also be argued that the tighter connection between the two transitions in the EU provides stronger support for the public governance leg of the interoperability strategy.

4. *Regulatory incentives for digital innovation*

to be completed

5. *Making the ICT sector sustainable*

to be completed

6. *Data management models*

to be completed

7. *Conclusions*

to be completed

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