The Disruptive Potential of Energy Digitalization:

A Comparative Analysis of German and French Policy-Mixes

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Abstract:

Decarbonization, digitalization and decentralisation are the most important factors presently influencing energy systems world-wide. Of those, digitalization is understudied and often only analysed from a technological perspective. Energy digitalization could however fulfil important monitoring and operational functions, in energy systems which will likely become more complex. This paper therefore chose to analyse to what extent energy digitalisation could implement itself in on-going energy transitions, and the extent of its disruptive potential. To investigate this question, we used Kivimaa's and Kern's (2016) framework on 'motors of innovation', which analyses sustainable policy mixes in terms of their destructive and creative potential. Germany and France were picked as case studies. The findings showed that France and Germany policy mixes are presently not suited for a wider digital transformation of their respective energy systems. These results therefore question the feasibility of such a digital transformation. Consequently, it is likely that digital tools will likely play an incremental role.

Keywords: *Energy Digitalization, Policy Mix, Creative Destruction, Multi-level perspective, France, Germany*

Word count: 11 094

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I thank my parents for everything and more.

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1. Introduction

Digitalization, as a process, is drastically changing our societies and economies (Castells, 2010). It is bringing forward structural changes, especially since the beginning of the 21st century, with the advent of interactive and mobile communication tools, such as mobile phones and tablets (Valenduc & Vendramin, 2017). Many have described this process as having the potential of being particularly disruptive to the way businesses operate and the way people interact, with some even describing it as the 4th industrial revolution (DiSilvestre et al., 2018; Renn et al., 2021).

Because digitalization has permeated our societies to an extent that cannot be overlooked, it will likely influence sustainable transitions which are currently ongoing (Kunkel & Tyfield, 2021). Digitalization will most likely play an important role in our ongoing energy transition (Menzel & Teubner, 2020). An increase of the part of renewable energies in worldly energy mixes has been ongoing, driven by our need to strive for less carbon-intensive energies. The intermittency of renewable energies is, however, a problem for current energy systems in terms of operation and distribution. It is generally accepted that the successful integration of new renewable energies into the energy grid requires a transition to a distributed energy system as opposed to the traditional centralized energy system of today (Ahl et al., 2019). Information and communication technology (ICT), as well as other digital technologies, in particular, will play a key role in facilitating the transition to a more decentralized and sustainable energy system (Teufel et al., 2019)**.** These include "a diverse array of generation, storage, energy monitoring, and control solutions" (Arup & Siemens, 2020). Indeed, due to the inherent complexity of distributed and decentralized energy systems, an increasing number of operations will need to be monitored and executed (Andoni et al., 2019). This is where new digital technologies could have an important role to fulfill. The interlinkages of decarbonization, decentralization, and digitalization, often also coined the 3Ds, are widely considered as being the most determining factors of influence for our future energy systems (DiSilvestre et al., 2018; Judson et al., 2020).

In terms of sustainable transitions in the energy sector, many researchers, however, relegate digitalization to a minor factor of influence (Sareen & Haarstad, 2021). Indeed, most papers on digitalization in the energy sector, focus on technological aspects. Few however have looked at the processes which lie behind digitalization, and the path it could take in the future (Judson et al., 2020). According to Sareen & Haarstad (2021), this has to change, and digitalization should, for them be considered a "key driver of transformative environmental innovation" and not merely as an overarching influencing factor (Sareen & Haarstad, 2021).

2. Setting the scene

2.1 Digitalization

2.1.1 Definitions

The meanings of several terms surrounding the *digital* are often used interchangeably and blur together. Nevertheless, three of them appear more frequently in the literature. Digitalization, digitization, and digital transformation are terms that are often seen but have different definitions depending on the field of research (Bockschecker et al., 2018). This paper will use the following definitions:

The term **digitalization** should be differentiated from the term**, digitization**, which refers to the "conversion of data from analogue to digital form" (Sareen, 2021). **Digitalization** can be defined as the "application of *digitization* to social and organizational processes", enabled by the increased connectivity and networking of digital technologies, enhancing communication, services, and trade between people, organizations, and things" (Evangelista et al., 2014; Sareen, 2021). Finally, **digital transformation,** a term mainly used by businesses, will be referred as "a fundamental change process, enabled by the innovative use of digital technologies accompanied by the strategic leverage of key resources and capabilities, aiming to radically improve an entity and redefine its value proposition for its stakeholders" (Gong et al., 2021).

2.1.2 Digitalization as a disruptive phenomenon

Digitalization has brought pervasive changes in all walks of life, at a fast pace. ICT devices have become ubiquitous. In 1990, there were only 10 million mobile phone users, compared to 5.3 billion today (Datareportal, 2022). With the advent of ICT devices, more people are now also internet users. In 1990, 20 million people were internet users, compared to more than 3 billion today. In the past 5 years, every day 640 000 people have used the Internet for the first time, which is more than the number of people presently being born per day (Roser et al., 2022; Ritchie & Roser, 2019). These trends have been observed world-wide. While some regions such as Africa, and South Asia, have been lagging behind in terms of mobile phone and internet users, it is expected that they will soon catch up. In sub-Saharan Africa, more people have access to mobile phones than to electricity (Economist, 2017).

Some argue that the largest change that digital tools have brought about is the scale at which digitization has progressed. Valeduc & Vendramin (2017) state: "We are now confronted with both a quantitative leap and an exponential growth in the collection, storage, and processing of digitised information".

All forms of digital technologies, be it phones, AI technologies, blockchain technologies, etc. continuously produce data, *structured and unstructured* (Ribeiro et al., 2015). This amount of data, which is present "too large and complex to fully capture" is defined as Big Data (Gudivada et al., 2015). Big Data is said to have the potential to unlock new opportunities for business and the scientific community alike, in a plethora of fields ranging from healthcare to nature conservation (Kelling et al., 2009; Shilo et al., 2021; Gudivada et al., 2015). Through Big Data, general operations of businesses could be optimized, while scientists could experiment with novel and more complex approaches (Degryse, 2016).

This rapid pace of adoption of ICT tools, and other digital technologies, is what has allowed for digitalization. With digitalization, digital transformative processes can occur. A common example that illustrates this process is that of new companies such as Uber and Airbnb, which through their early adoption of digital tools within their business model, brought forward drastic changes in the labor markets of countries in which they competed.

Uber and Airbnb competed against traditional firms in the fields of transportation and travel by allowing anyone to rent out their house to vacationers or to become a driver, through a mobile app. As the vice-president of the French conseil national du numérique Christine Balagué explains: "Any individual equipped with a mobile phone could now 'become a producer, create services, or at least place services on offer, to make a bit of extra money" (Degryse, 2016). This simple business model has led to drastic changes in the way the labor market has been traditionally conceived, going beyond the simple employee-employer relation. One could here talk about a process of creative destruction in the labor market (Valendrin & Valenduc, 2017).

Greater access to ICT devices and digital technologies has therefore led to the digitization of an unprecedented amount of data, allowing for digitalization, which by "enhancing trade and communication" has enabled disruptive transformative processes within societies world-wide.

2.1.3 Digitalization and Sustainability

Many hopes are set on digitalization as an enabler of sustainable transitions. The sustainable development goals (SDGs) themselves describe how digital tools can be used to achieve sustainable development. Target 9c of SDG 9: *Industry, Innovation, and Infrastructure*, for example, states that one should "significantly increase access to information and communication technologies, and strive to provide universal and affordable access to the internet in the least developed countries by 2020" (UN, 2022). Similarly, SDG 5: *Gender Equality* states with target 5b that one should "enhance the use of enabling technology, in particular information and communications technology, to promote the empowerment of women" (Van der Velden, 2018). Sustainable industrialization, given by SDG 9, in particular, is quite dependent on digitalization to achieve decoupling between economic growth and negative environmental externalities (Kunkel & Tyfield, 2021).

Some drawbacks to digitalization have however been mentioned in the literature. While digital tools can bring efficiency gains, they are often resource-intensive in terms of energy and material usage. Blockchain infrastructures for example are extremely energy intensive. For 30 million bitcoin transactions conducted in 2017, 30 billion kWh had to be used, accounting for 0.13% of global power consumption at the time (Wu & Tran, 2018). Efficiency gains may also lead to what some call a digital rebound effect, a concept closely aligned to that of the Jevons paradox, where efficiency gains lead to a resource to be used more intensively, due to falling costs (Coroama & Mattern, 2019; Kunkel & Tyfield, 2021). The digital rebound effect was studied by Lange et al. (2020). By using an analytical model, the authors found that ICT tools led to higher energy usage when accounting for direct effects linked to the production, usage, and disposal of the latter, as well as through the economic growth it induced. The question of whether digitalization induces more energy consumption and demand is however highly debated (Xu et al., 2022). Another concern is data security and privacy. Especially with infrastructures as critical as energy systems, cybersecurity is of utmost concern (Rajavouri & Huhta, 2020).

Despite these drawbacks, the negative aspects of digitalization are understudied, and policy-makers, inter-governmental businesses, and the private sector alike, widely view digitalization as a way to achieve sustainable industrialization compatible with economic growth, while also supporting its supposed disruptive potential (Kunkel & Tyfield, 2021). Such a view is for example supported by the World Economic Forum (WEF), which investigated the potential of digitalization in 10 different industries. The results showed that the presently untapped potential of digitalization could bring economic gains, compatible with environmental limits (WEF, 2017; Figure 1). The same has been assumed in the energy sector (Figure 1; WEF, 2017). According to the WEF, the oil and gas industry, as well as the general electricity sector, could bring cumulative gains of several trillion dollars (Figure 1).

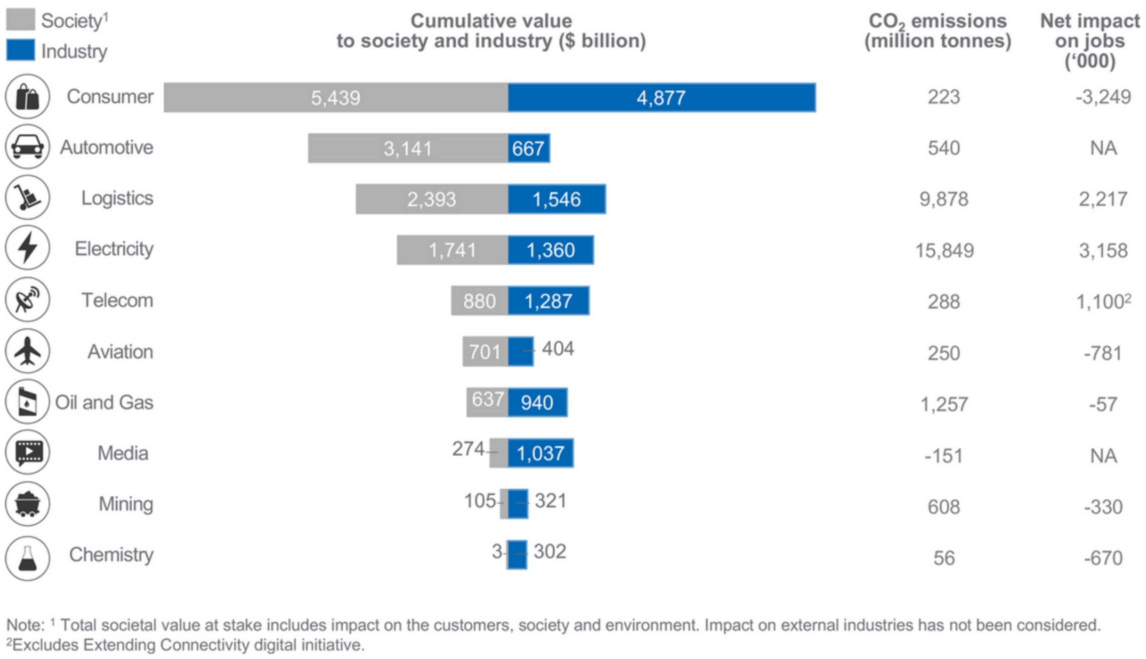

Figure 1*. The "combined value" to industry and wider society of digital initiatives across ten industries, cumulatively between 2016-2025 (WEF, 2017).*

The World Economic Forum, in collaboration with Accenture, developed a so-called value-at-stake framework, to investigate the impact digitalization could have on 10 different industries. They not only looked at the monetary value gained through digital innovation but also at societal benefits, namely environmental gains and benefits for customers. The value of these social benefits was then assumed in \$. They found that digital transformation in these 10 industries could attain a cumulative value of \$ 100 trillion if realized between 2016-2025. All of these benefits would be attained by significantly lowering CO_2 emissions in all 10 industries, excluding the media sector.

2.2 Digitalization in energy systems

2.2.1 Functions of Energy digitalization

The oil and gas sectors have already used some forms of digital technologies for decades. To uncover new oil fields during the exploration phase, oil companies have for example used seismic imaging technology for 80 years (Mittal et al., 2017). This had however no discernable impact on the general operations of oil and gas companies. For the future of energy digitalization, deeper-reaching changes are expected to occur, altering how energy is generated and distributed, throughout the whole value chain (Küfeoglu et al. 2019). These changes are said to be inevitable (Sareen & Haarstad, 2021).

Within energy systems, in particular, digitalization is said to have the potential to provide win-win situations, particularly through efficiency and flexibility gains (Lange et al., 2020). Actors in the energy sector also share a consensus that digitalization could help achieve all pillars of the energy triangle: energy security, economic growth, and sustainability (Swiatowiec-Szczepańska & Stępień, 2022).

At first, energy digitalization was mainly seen as a lever for energy-saving opportunities (Ghobakhloo & Fahti, 2021). As energy digitalization has gained traction, more opportunities have, however, been uncovered. Weigel & Fischedic (2019), through a review of the literature, found that energy digitalization could bring the following broad benefits: (1) system stability, (2) environmental protection, (3) energy demand reduction, (4) revenue enhancement, (5) cost reduction and (6) customer satisfaction. Supposedly, energy digitalization could therefore allow for economic growth, compatible with sustainability concerns. Similarly, Ghobakhloo & Fathi (2021), through a systematic literature review, uncovered 10 different functions which energy digitalization could fulfill in the near future (Table 1). These 10 functions show that energy digitalization could have a far-reaching impact across the whole energy value chain.

Table 1. *10 functions of digitalization for energy sustainability* (Ghobakhloo & Fahti, 2021).

The authors of the paper, using the ISM supply chain assessments model, uncovered 10 functions of digitalization across the whole value chain, in terms of energy sustainability, going against the pre-conceived notion that digital tools are only good for efficiency gains. I made the table and adapted it to simplify it for the reader.

Functions	Description
1. Energy demand sector digitization (EDSD)	Electricity end-use digitization will bring efficiency gains
2. Energy sector digital transformation (EST)	Digitalization will change how energy is produced, delivered, and consumed
3. Improved methods of production (IMP)	Industrial production will be more energy efficient
4. Improved production management (IPM)	Real-time production management will be more efficient
5. Improved production planning and control (IPPC)	Manufacturers will be able to make their operations and processes more efficient
6. Informed decision-making (IDM)	Large amount of data to optimize energy usage will be available
7. New business model innovation (NBMI)	New, more service-oriented business models will appear
8. Smart energy management systems (SEMS)	Grid operators and energy consumers will have real-time control of their energy needs, consumption and costs
9. Sustainable new product development (SNPD)	Product development will be more sustainable and efficient
10. Value chain digitization (VCD)	Value chains will be more flexible and efficient

This view is also supported by others. Impacts of energy digitalization, according to the International Energy Agency (IEA), will be particularly felt in transportation, with higher automation and electrification of vehicles, within buildings and industries, with better optimization of demand response to peak loads and general optimization of energy usage, as well as in the production side of the energy sector in general, including the coal and gas industry (IEA, 2017). The whole energy system could therefore digitally transform itself.

2.2.2 Digital technologies, as enablers of energy digitalization

Many different technologies will have a role to play in the digitalization of our energy system. Energy digitalization is brought forward by different technologies which can be separated into three categories: Digital technologies and techniques, physical energy technology, and connectivity (Judson et al., 2020; Figure 2).

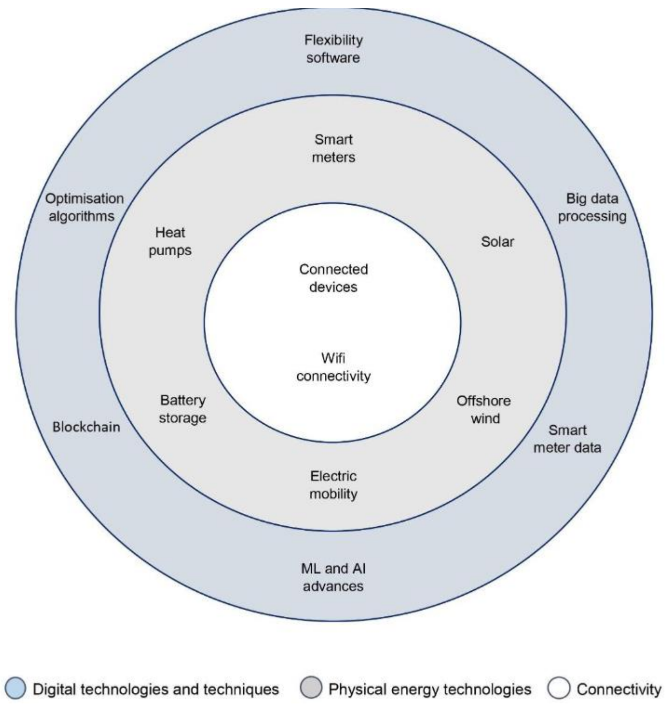

Figure 2. *Important technologies shaping energy digitalization (Judson et al., 2020).*

The figure is directly taken from Judson et al (2020). The pictured technologies were chosen by British energy stakeholders as having the most disruptive potential, as well as being the ones necessary for a wider energy digitalization. Judson et al. (2020) obtained these results by holding 18 semi-structured interviews with relevant specialists, as well as through online workshops.

Digital technologies and techniques generally allow for greater efficiency and optimization of energy demand, made possible by insights gained through data flows coming from physical energy technologies. Finally, without connectivity, e.g. the internet, no flows of data can be communicated. The digitalization of our energy system relies on all three categories to progress (Wu et al., 2021, Judson et al., 2020).

Technologies that could be integrated into the digitalization of our energy system, have different levels of maturity. Electric vehicle sales are for example rapidly expanding, while smart meters and heat pump installations are increasing (Noussan et al., 2020; World Economic Forum, 2017; IEA, 2017). On top of that various industries in the transport, building, and heating sectors have already started to introduce digital technologies, to gain data insights, as well as to automate processes for efficiency gains (IEA, 2017). However, to attain all the benefits set out by Ghobakhloo & Fathi (2021), a wider digital transformation of our energy system is expected. Many technologies will have a role to play, to fulfill the general vision that is supported by most energy stakeholders of a consumer-oriented, decentralized, decarbonized smart grid (Figure 3). Indeed, energy stakeholders see the necessity of a transition from our present "dumb" electricity grids, which are highly centralized, to so-called smart grids (Skjølsvold et al., 2015).

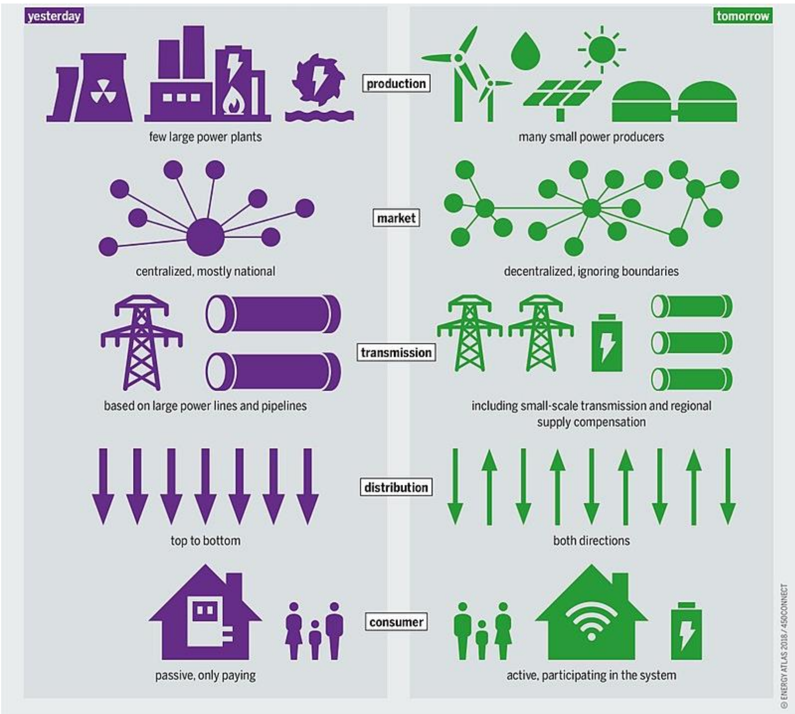

***Figure 3**. Staying big or getting smaller: expected structural changes in the energy system, made possible by the increased use of digital tools (Stockmar 2018).*

This illustration was made for the Heinrich-Böll Stiftung, a foundation of the German Green Party. It illustrates expected changes of present energy systems that digital tools have the possibility to enable.

2.2.3 A vision for the future of energy digitalization

A smart grid is defined by the US Energy Department as the following: "*A Smart Grid uses digital technology to improve the reliability, security and efficiency (both economic and energy) of the electrical system* from *large generation, through the delivery systems to electricity consumers and a growing number of distributed-generation and storage resources*." (Dileep, 2020). Smart grids are enabled by the Internet of Things (IoT), which can be described as physical objects or groups of such, communicating and exchanging data, through processing power, software, sensors, or other technologies, which allow for efficiency and optimization gains (Wu et al., 2021). Such physical objects are smart sensors or smart household appliances, which allow consumers to e.g regulate lights at a distance (Sovacool & Del Rio, 2020). At a larger scale, it is however expected that IoT-enabled smart meters will play an important role.

Smart electricity meters, devices that communicate data on electricity consumption, are a prerequisite to this transition. They could fulfill a dual function if implemented into the electricity grid. First, they would allow energy consumers to be more active within their energy market by letting them look up data on their energy consumption or even production, through the ICT devices (Vitiello et al, 2022). Secondly, smart meters would also allow for remote grid monitoring by energy operators, allowing them to follow from a distance the changes in energy demand through data provided by smart meters. This would facilitate energy operators to balance and optimize the electricity grid in real time (Skjølsvold et al., 2015).

This is especially relevant for the decarbonization of our electricity grid. With solar and wind power, intermittence issues pose a problem. A smart grid would be beneficial, as it would allow to smooth out demand peaks in electricity usage (Baidya et al., 2021). Intermittence issues could also be solved by energy storage technologies, especially battery storage technologies, which could be integrated into a smart grid. These operate on the general idea that excess energy produced by renewable generation when the latter's capacity is high, would be stored to be used later on when the necessity would arise (Ibrahim et al., 2008). Such a function could also be fulfilled by electric mobility infrastructures. The Vehicle to Grid (V2G) is a concept based on the idea that the battery of electric vehicles could be used to regulate electricity demand and supply, by storing surplus electricity into plugged-in cars, which could then be re-used later on (Shaukat et al., 2018).

Heating and cooling infrastructures could equally benefit from smart grid applications. Heat pumps, district heating, and cooling could both be integrated into a smart grid to form smart energy systems, whereas, heating and cooling capabilities could be both optimized and rendered more efficient (Lyons, 2019).

As with other digital applications, the adoption of the smart grid is hindered by concerns about security, privacy, and trust. Blockchain technologies are seen as particularly promising to counter-act these problems (Wu et al., 2021). Indeed, Blockchain technologies allow people to conduct transactions without intermediaries securely and anonymously (Ahl et al, 2019). With Blockchain 2.0, these processes and transactions could be fully automated, with so-called smart contract models. In the energy sector, Blockchain 2.0 could be used by consumers to conduct direct Peer to Peer (P2P) trading for their electricity, without the need for energy brokers, thus lowering the final cost of their electricity bill (Teufel et al., 2019). Other digital techniques, such as optimization algorithms and flexible software also have their role to play, in particular at the level of the electricity production of renewables (Kangas et al., 2021).

As described, all technologies, while fulfilling a singular function by themselves, become more powerful when combined, permitting a resilient smart grid, allowing for energy optimizations at the smallest of scales, within large industries and households.

2.2.4 The future path of energy digitalization and its present constraints

The path energy digitalization will take is yet unclear. Nevertheless, an ever-increasing number of smart energy services have been developed to facilitate the digitalization (datafication) of our energy systems, providing benefits to consumers (IEA, 2017). The full deployment of smart energy services at a larger scale has been lagging behind, slowing down the transition of our energy systems (Veskioja et al., 2022).

Indeed, some trends are constraining the way digitalization is being developed and implemented. As described above, two other drivers particularly influence the digitalization process within our energy systems: decarbonization and decentralization. DiSilvestre et al. (2018) found that digitalization, decentralization, and decarbonization, the 3D's, are already changing power infrastructures in the USA, the EU, and China alike.

Decarbonization & Decentralization

Digitalization in the energy sector, through the form of a smart grid, is particularly constrained by the number of renewables present in an energy mix. The whole vision of a digitalized energy system, is indeed mostly pushed forward by the need to account for the intermittency of renewables, as well as their more spatially diffused power generation, which in turn pushes decentralization measures forward. Without renewables, battery storage technologies have also a more negligible role to play. Another constraint is the fact that some sectors, particularly those of transport and heating, need to be electrified if decarbonization goals were to be met. Both of these are today mostly reliant on fossil fuels. Electric mobility (e.g ships, cars, trains) as well as heat pumps, could here provide solutions.

Secondly, a structural change within our energy systems needs to occur. Traditional power generation, on which our present "dumb" electricity grids are built, is reliant on centralized power structures, which do not necessitate a wider digital transformation of the sector. Finally, related to decentralization concerns, digitalization has an important role to play in terms of consumer services. But there, cultural aspects come into play as consumers need to be receptive to such technologies. Smart meter implementation, for example, was met by huge protests in several countries (Geels et al., 2019).

Regulations

An energy system pushed forward by the 3Ds, also needs to be supported by regulatory changes. First, the interconnectedness of a digitalized energy system needs to be taken into account (Sareen & Haarstad, 2021). Indeed, within a more complex digitalized energy system, the barriers between different sectors become increasingly porous. With V2G, for example, electric mobility would be linked to the general electricity grid, for optimization purposes. Presently, regulatory frameworks are, however, mostly "siloed" (Sareen & Haarstad, 2021).

Secondly, new technologies need standards to be implemented within our existing energy systems (Judson et al., 2020). Smart contracts based on the Blockchain 2.0 technology are presently not viable in most countries, as energy markets do not allow energy transactions without an intermediary (Valdivia & Bancell, 2022).

If fulfilled, a digitalized energy system would be highly beneficial. Grubler et al. (2018) modeled a Low Energy Demand scenario, in which energy provisions and consumption would be digitalized and consumer-oriented. They found that their scenario fell within the boundaries set by the Paris Agreement, which seeks to limit global warming at 1.5 °C with the particularity that their scenario did not include negative emission technologies.

But to fulfill the vision set out by energy stakeholders of a consumer-oriented, decentralized, decarbonized smart grid, our present energy systems will need to be destabilized to allow for transformative digital changes to pave the path for the sustainable transition of our energy systems. New, presently niche, technologies will need to supplant pre-existing ones to allow for the datafication of energy consumption, while regulations will need to be put in place to accommodate for potential new digital services. These replacements could be enabled by creative destructive processes, permitted by regulatory and institutional changes.

3. Theory

3.1 Transition theory

This paper will mainly draw from socio-technological transition theory, with a focus on the Multi-Level Perspective (MLP) framework theorized by Geels (2002) and the concept of creative destruction, coined by Joseph Schumpeter.

Energy systems can be defined as socio-technological systems, meaning that they are influenced by both social and technological variables (Kern & Smith, 2008). Linked to this, socio-technical transitions are defined as processes that transform socio-technological systems, over an extended period (Rotmans et al., 2001). Geels (2002, 2004) and Rip and Kemp (1998) have through historical case studies tried to understand how transitions are enabled and suggested the MLP framework as a useful tool for analyzing socio-technological transitions.

The MLP framework is best described by Geels (2010), who defines it as a "framework for understanding sustainability transitions that provides an overall view of the multi-dimensional complexity of changes in socio-technical systems". The MLP framework differentiates between three analytical levels: the landscape, regime, and niche level. The landscape level is often regarded as the most stable which qualifies as a profound external factor and heavily influences the regime level (Geels, 2011). The regime level includes semi-structured rules, which can encompass cultural practices, regulations, and laws (Geels, 2002). At the niche level, new and even radical innovations emerge, with the potential to influence the other analytical levels. Niches cannot, however, always influence the other levels, if lock-in mechanisms are present at the regime level (Geels, 2011). If one were to relate energy systems to the analytical levels, niches would refer to new technologies which have been competing with the established energy regime, such as renewables energy technologies or battery storage systems, while at the landscape level one could include decarbonization measures which are mounting worldwide, which is pressuring present energy systems.

The MLP framework has been widely used within historical and predictive studies of energy transitions, as well as, for example, in the fields of mobility, finance and transportation (Yang et al., 2022).

3.2 Creative destruction

Sustainable transitions theory widely draws from the idea that socio-technical regimes need to be destabilized, so that more sustainable forms of the regime can take their place. This idea is based on the concept of creative destruction, popularized by Austrian economist Joseph Schumpeter (David, 2017; Kivimaa & Kern, 2016). Borrowing the concept of long cycles of economic development set out by economist Kondratiev, Schumpeter theorizes how transition phases between two stable cycles of economic development are characterized by the appearance of "innovative clusters", which through disruptive technological innovations bring forward new socio-technological regimes. Transition phases are also characterized by the appearance of new business models, as well as new institutional frameworks, which can lead to creative or destructive changes (Valenduc & Vendramin, 2017). To summarize, creative destruction can be described as a process where newcomers, through new technology or innovation, challenge older firms rendering the latter obsolete, effectively leading incumbent firms to be kicked out of the market. An example of this occurrence is given through the history of the phone company Nokia. At its peak in 2007, the company had a market share of 50% in the sector of mobile phones, worldwide (Simonen et al., 2020). With newcomers Samsung and Apple, Nokia's market share dropped drastically, as its competitors offered innovative products, namely smartphones. Subsequently, Nokia closed its mobile division in 2013, only six years after it had reached its peak market share, selling its remains to Microsoft (Simonen et al., 2020).

In other cases, however, empirical evidence has shown that incumbent firms can absorb new technological innovations brought forward by challenging firms, preventing a creative destructive process to occur. This process is known as creative accumulation. Bergek et al. (2013), for example, describe the process of creative accumulation, in the field of hybrid vehicles. There Toyota as an incumbent firm managed to gain an undeniable advantage over its competitors, through its long-standing expertise in car-building. While some aspects of a car can be considered substitutable, a car's performance is mainly determined by non-substitutable factors, such as a car's fuel efficiency, safety, or price. This is a problem for challenging firms, as they have to catch up to the level of car performance of companies that have had decades to perfect their cars. Toyota eventually bought most of the companies which had challenged them in that specific field (Bergek et al., 2013). Incumbent firms can therefore often play an important role in terms of niche technological development, especially when faced with external pressures (Steen & Weaver, 2017).

Nevertheless, processes of creative destruction have been widely assumed to be beneficial and necessary for economic growth. Basing their theory on Solow, Aghion & Howitt (1990) in a paper titled "A Model Growth based on creative destruction", the authors theorize that growth is mainly driven by technological innovations in opposition to the accumulation of capital. This view has been adopted by a large number of policy-makers, who put technical innovations at the forefront of their economic policies (Davidson, 2019).

3.3 Creative destruction in energy systems

Energy systems, as socio-technical systems, are particularly subject to lock-ins at the regime level, due to institutional, technological, infrastructural, and behavioral factors (Fouquet, 2016). This makes energy systems susceptible to path dependency. Path dependency stipulates that historical occurrences and established infrastructures influence the path such a system takes, or, more succinctly, that “history matters” (Aghion et al., 2019; Lovio et al., 2011). Concerning energy systems, such a path dependency is demonstrated by our reliance on fossil fuels, on which most of our energy infrastructures are built upon. A common example is petrol-powered cars, around which most of our transportation system is built. Switching to electric cars would entail a huge overhaul of the present infrastructures, as well as of all businesses which are linked to the car sector in terms of logistics and production of parts (Lovio et al., 2011). This raises the question of who would finance such a transition. If financed by incumbent companies, this money flow will likely be redirected to strengthen the regime in which they have established networks. These switching costs explain in part why energy systems are particularly subject to path dependency (Aghion et al., 2019).

Nevertheless, with the necessity to decarbonate our present energy systems, new paths need to be created. Path creation is for many brought forward by technological innovations, which seek to destabilize the present regime (Aghion et al., 2019). Incumbent firms, which are met with mounting pressure to decarbonate, will likely be at the origin of some disruptive innovation clusters. These will likely, however, try to balance out the necessity to decarbonize with a strategy that seeks to limit switching costs (Lovio et al., 2011). This observation is also supported by Aghion et al. (2012), who found that incumbent firms in the energy sector tend to redistribute investment to technologies they are already familiar with. In return, this would entail that the path which could be created by incumbent firms, would likely try to conform to some extent to the existing technological pathways.

New, bolder paths will however be required in the future, while our energy systems will need to be transformed, especially when one considers the speed and scale at which climate change is progressing. Incumbent firms, which are more likely to follow preconceived technological pathways, are however more likely to pursue optimization strategies rather than transformative ones (Steen & Weaver, 2017). This is where new entrants, as well as innovations, will likely have a role to play, as they can move forward with processes of creative destruction, which would aid in the transition of our energy systems and the creation of alternative structures.

With the need to transform our energy systems, many new technologies and energy services at the niche level have showcased potential. Transposing these new technologies from the niche to the regime level will be influenced by a multitude of factors. Governmental policies and regulations will, however, be particularly relevant and are generally seen as a major driver (Henderson & Sen, 2021). Indeed, considering that energy systems are particularly susceptible to lock-ins, new technologies need heightened institutional support (Lovio et al., 2011). Some argue that these policies, to move forward with important transitions of energy systems, need to include creative destructive components (Kivimaa & Kern, 2016)

3.4 Aim and Research Question

Digitalization, as a general phenomenon, has already brought pervasive changes in our social and economic lives, and energy digitalization could enable such phenomena in present energy regimes. Energy digitalization is perceived and envisioned as a disruptive process that could overhaul our energy system and is strongly linked to the present decarbonizing energy transitions which are on-going. It holds the promise of economic growth which could be compatible with environmental and sustainability concerns. In addition, energy digitalization is concordant with a general view of techno-optimism which is supported by many governments, for example in regard to negative emission technologies (Davidson, 2019). Are national governments, however, ready for such a digitalized energy transition? As discussed, governmental policies have a particularly important role to play in regard to energy transitions. This paper will, through a comparative case study of France and Germany, try to provide tentative answers to that effect.

The vision of a decentralized, decarbonized, and consumer-oriented smart grid is supported by the EU under its *Action Plan on the digitalization of the energy sector*, launched in 2021 (European Commission, 2021). This program envisions a digital transformation of the present electricity grids of EU-members to accommodate for a European-wide interconnected electricity grid. France and Germany, therefore represent interesting case studies. As important members of the EU, their efforts in terms of energy digitalization will likely have repercussions on the success of this EU vision. Additionally, the two countries were chosen as both countries are pursuing very different energy system transitions. Both energy regimes, therefore, diverge, which will expand the ensuing analysis. However, with France and Germany both being a part of the EU, it provides a general policy landscape that is still grounded in similitude.

Considering how reliant our future energy transition is on the promise of its future digitalization, which could enable wider decentralization and accentuated decarbonization, this paper will investigate the present state of digital transformation of our energy systems, informed by theoretical and empirical observations of how digitalization has evolved and will likely evolve in the future. It will also try to gain an outlook on the disruptive potential of energy digitalization in Germany and France.

Therefore, this research paper will anchor itself around these two research questions:

- ➔ **R1: To what extent can digitalization play a role in the ongoing energy transitions of France and Germany?**
- ➔ **R2: To what extent can energy digitalization evolve to be a disruptive phenomenon in France and Germany?**

4. Methods

4.1 Conceptualization

Energy digitalization is driven by different digital technologies and techniques. These technologies can emerge by themselves or with heightened institutional support, which is normally necessary for energy regimes, considering their locked-in nature. This paper will therefore try to answer the research question from a policy-perspective, particularly through a policy mix analysis. Indeed, an analysis of policy mixes, meaning "a set of different and complementary policy instruments to address the problems identified", gives a cross-sector overview of energy measures in place in France and Germany. This is important, considering that digital tools and technologies can be implemented in the heating, electricity, and wider energy sector. The analysis of the energy policy mixes, of both France and Germany, was made through the usage of an analytical framework developed by Kivimaa & Kern (2016). This framework allows for the general analysis of policy mixes but also encompasses a feature that differentiates between creative and destructive policies, allowing for the analysis of the disruptive potential of energy digitalization. Indeed, without, disruptive policies which encourage creative destruction, the path dependency of energy systems could make energy digitalization a mere niche phenomenon, with would have no wider implications for the present energy regime. The analytical framework is developed further-down (Table 2).

The framework by Kivimaa & Kern (2016) was used to gather a general idea of present energy policies in place in Germany and France in three sectors where energy digitalization can fulfill its promises: heating, mobility, general efficiency measures, and the electricity sector. To get a more nuanced understanding of energy digitalization measures in France and Germany, policies that specifically mentioned digitalizing measures were singled out, while special attention was given to policy measures that specifically mentioned the physical energy technologies seen as the most important drivers of energy digitalization by Judson et al. (2020).[1]

[1] See Section 2.2.2, Figure 2

4.2 Analytical Framework

Table 2. *The analytical framework of Kivimaa & Kern (2016) distinguishes creative and destructive policies.*

Overall	Code	Name	Policy Instruments
Creative	C1	Knowledge creation, development and diffusion	R&D funding schemes, innovation platforms and other policies aiming to increase knowledge creation and diffusion through networks; subsidies for demonstrations; educational policies, training schemes, coordination of intellectual property rights, reference guidelines for best available technology.
	C2	Establishing market niches/market formation	Regulation, tax exemptions, market-based policy instruments such as certificate trading, feed-in tariffs, public procurement, deployment subsidies, labelling.
	C3	Price-performance improvements	Deployment and demonstration subsidies enabling learning-by-doing; R&D support (cost reductions through learning).
	C4	Entrepreneurial experimentation	Policies stimulating entrepreneurship and diversification of existing firms, advice systems for SMEs, incubators, low-interest company loans, venture capital; relaxed regulatory conditions for experimenting.
	C5	Resource mobilisation	Financial: R&D funding, deployment subsidies, low-interest loans, venture capital. Human: educational policies, labour-market policies, secondment of expertise.
	C6	Support from powerful groups/legitimation	Innovation platforms, foresight exercises, public procurement and labelling to create legitimacy for new technologies, practices and visions.
	C7	Influence on the direction of search	Goals set and framing in strategies, targeted R&D funding schemes, regulations, tax incentives, foresight exercises, voluntary agreements.
Destruction	D1	Control policies	Policies, such as taxes, import restrictions, and regulations. Control policies, for example, may include using carbon trading, pollution taxes, or road pricing to put economic pressure on current regimes. Banning certain technologies is the strongest form of regulatory pressure (e.g. phase out of fluorescent light bulbs).
	D2	Significant changes in regime rule	Policies constituting, for example, structural reforms in legislation or significant new overarching laws. Historic examples of major rule changes include the privatisation and liberalisation of electricity markets in the 1990s which completely changed the selection environment within which utilities were operating.
	D3	Reduced support for dominant regime technologies	Withdrawing support for selected technologies (e.g. cutting R&D funding, removing subsidies for fossil fuel production, or removing tax deductions for private motor transport).
	D4	Changes in social networks, replacement of key actors	Balancing involvement of incumbents for example in policy advisory councils with niche actors (as attempted in the Dutch energy transition programme through the transition platforms) (Kern and Smith, 2008); formation of new organisations or networks to take on tasks linked to system change.

To analyze the creative and destructive properties of policy mixes, Kivimaa and Kern (2016) based on sustainable transition literature, including the MLP framework, propose seven creative analytical categories and four destructive analytical categories, each category corresponding to specific policy instruments (Table 2). Justifications, drawing from sustainable transition literature, can be found in the paper by Kivimaa and Kern (2016). The creative categories are mainly based on the functions of Technological Innovation Systems (TIS) and strategic niche management theory. All seven creative functions are linked and supposedly, strengthen one another. When policies for the emergence of one technology are present in all seven categories, a self-reinforcing mechanism allows for the eased generalization of the former (Kivimaa & Kern, 2016). Concurrently, this means that all seven categories influence each other. As an example, one first needs R&D investments in innovation (C1), to then establish a market for that innovation (C2), while deployment subsidies can allow said innovation to finally emerge (C5). Finally, the destructive categories were developed by Kivimaa and Kern themselves, based on existing literature. The categories mainly draw from the concept of creative destruction linked to the MLP framework.

4.3 Data collection

The general pursued method was that of a policy mapping exercise. Data were extracted from the IEA policy database, which can be found here. From there data for France and Germany wereextracted for 2010-2022. This period was considered as being the most relevant to our ongoing energy transitions in Europe. Indeed, one could consider that pressure to decarbonize for governments significantly mounted after the 2015 Paris agreement.

Policies were selected on the basis that the instruments concerned the sector of mobility, heating, as well as the general renewable energy sector in terms across the whole value chain. This therefore excluded in the case of France's specific policies concerning the nuclear sector, or the gas sector in Germany, as these are less relevant to the digitalization of the grid. For the mobility sector, it was decided to only include policy measures that pertained to cars or buses, excluding therefore planes, trains, or ships. Policies that have been enforced and are in force presently were included. Policies that are planned but not in force were excluded from this analysis. Additionally, only nationwide policies were included, excluding regional and municipal policies.

Focus lied on six different sectors. Four of them, **electricity, efficiency** and **heating, and mobility,** were used to get a general idea of influencing policies in both countries. All of them showcase the most potential for digitizing applications. Two additional categories, **renewables** and **battery storage** were singled out. Indeed, in the case of Germany, it was found that 15 of the 78 policies concerned renewables, which represents a considerable amount of data. To facilitate analyses these data were not included in the general electricity field. The same reasoning applies to the battery storage category. Finally, a *general* category, with policy measures impacting the whole energy system was also set out, when the sectors were not specified.

Of the 103 available polices for Germany between 2010-2022, 68 were chosen. For France, these numbers were 73 and 35 respectively. When several instruments were presented on one IEA policy page, single policies were given their code Therefore, the number of policies that were kept rose to 44 policies for France and 78 for Germany. All selected policies without their detailed description can be found in Appendix II and Appendix III.

Following this, each single policy measure was assigned to the corresponding category code from Kivimaa & Kern's (2016) analytical framework. Decisions were based on the specific type of policy instrument and by basing oneself on a background search of energy regimes in place in Germany in France. Additionally, the justifications provided by Kivimaa & Kern (2016) for each category in their paper are quite extensive.

Finally, policies mentioning digitalizing strategies were put aside. In the case of France, this included seven policies, while in the German case, it was the case for 11 policy measures.

4.4 Limitations

They are several limitations to the data. As mentioned on the IEA website (IEA, 2022), the data is not exhaustive, meaning that several policies, which could have implications for the energy transition are missing. No better database could however be found and the latter was chosen as it was also used by Kivimaa & Kern (2016). Finally, a general comparison of the chosen policies was made through another database, https://climatepolicydatabase.org/. This allowed me to confirm that the IEA data included the most important energy policies in regard to both selected countries. Additional policies could have been snowballed, but I ultimately decided against it, as it would go against replicability criteria. It would also have rendered comparative analyses more difficult. Indeed, in the case of the IEA database, the data is collected by the same organisations for both countries (IEA, 2022). Nevertheless, the policy mix reflects the general trends which are shaping the energy transitions of both Germany and France. Considering that energy digitalization places itself in the context of the energy regime of both countries, some conclusions can still be developed.

4.5 Energy Regime of France and Germany

According to the Digital Economy and Society Index (DESI), which seeks to monitor the digital performance of EU countries, France and Germany have a relatively similar set of digital capabilities (European Commission, 2022; Appendix I). Both are slightly above the EU average according to the DESI indicator (Appendix I). The background will therefore mainly focus on the energy regimes of both countries.

4.5.1 France

Following the oil crisis of 1973, the French state, which was until then heavily dependent on oil imports from the Middle East for its primary energy needs, decided to transition to an energy system that would be heavily based on nuclear energy (Solomon & Krishna, 2011). Between 1971 and 2001, 58 nuclear reactors would be built in France, with nuclear energy providing the equivalent of 100 million tons of oil by 2008 (Solomon & Krishna, 2011). Until today, the French energy sector is heavily dependent on nuclear energy, which in 2020 provided 69% of all electricity, as well as 36% of all energy used in France (Ritchie & Roser, 2022). It should be noted that France has a relatively low electricity price per kWh compared to other EU countries. In the second half of 2021, the price of electricity stood at 0.2022 € per kWh in France, which is lower than the EU average of 0.2369 € (Eurostat, 2022).

This transition to nuclear energy was successful for three reasons. Firstly, Electricité de France (EDF), which enjoys a public monopoly on the generation and distribution of electricity in France, standardized the planning and building process of nuclear plants, which brought the final building costs down. Additionally, public support for the nuclear state program, which was first relatively low, grew, as the French state silenced any dissenting voices and successfully managed to sway public opinion on the matter. Finally, no alternative, which could adequately meet the energy needs of France, was available (Solomon & Krishna, 2011).

The 21st century saw a change in the way the French energy market was structured. In 1996, an EU directive was adopted that sought to liberalize the internal energy market of its state members in terms of gas and electricity (Debregeas & Plihon, 2021). Being bound to this, France took the necessary steps, and in 2004, EDF which had been nationalized in 1946, was privatized and restructured to become a limited-liability corporation under private law (Poupeau, 2020). EDF also had to separate itself from its gas division. The gas division called Gaz de France (GDF), after a merger with SUEZ in 2008, renamed itself ENGIE in 2015. The French State presently only owns 26% of ENGIE's shares, but still has a larger say in the operations of EDF, of which it owns 86% of the shares (Debregeas & Plihon, 2021). While both Engie and EDF still have the largest share in the market of electricity retail it keeps eroding, as new actors both international and national, have emerged, challenging both of them in that field. In the domain of electricity production and networks, the historical actors ENGIE and EDF still have a *de facto* monopoly, with EDF controlling all nuclear and 70 % of hydro-electric power in France (Debregeas & Plihon, 2021).

A new project, coined *Hercule*, was brought forward by the French government in 2019. It sought to further liberalize the French energy production and transmission system, by splitting EDF into two entities: EDF vert and EDF bleu. EDF bleu, state-owned would be responsible for the nuclear and hydroelectric sectors as well as for high-tension electricity networks (Beeker, 2019). EDF vert would be further privatized with 35% of its assets put into the stock market and given responsibility over everything else including renewable energies, low-moderate tension electricity networks, and customer service (Beeker, 2019). This proposal was met by opposition from syndicates and the public alike, as they feared that electricity prices would rise. The project was put on hold but was expected to be revived in the second term of president Macron (LeFigaro & AFP, 2021). With the Ukraine war, this plan was cast aside as it was decided that EDF would be fully nationalized again in the future to account for the heightened electricity prices (Rose & Hummel, 2022).

Presently, the French energy and electricity market is deemed to be highly centralized, with a strong reliance on nuclear energy, which prevents decentralized and renewable energy systems to emerge (Poupeau, 2020). In 2021, solar and wind power only accounted for 10% of all French electricity production (Ritchie & Roser, 2022).

4.5.2 Germany

Historically, Germany has been heavily reliant on coal for its energy and electricity needs, as it is one of the only electricity sources that the country can domestically produce (Müller -Hansen et al., 2021). In 1985, coal accounted for 62% of Germany's electricity production (Ritchie & Roser, 2022). Coal was and continues to be heavily subsidized by the German state. Between 1958 and 2008, the coal sector received around 295 billion € of subsidies, which were only reduced for the first time in 1997 (David, 2017). Today, coal has a smaller share within the energy mix of Germany as it accounts for 15% of energy production and 30% of electricity production (Ritchie et al., 2022). Renewables have however become important to Germany's electricity mix in particular, largely due to extensive policy measures.

Central to German energy policy and its *Energiewende (Energy transition)* is the Erneuerbare-Energien-Gesetz (EEG), which can be translated to the Renewable Energy Act. Put in place in 2000, it brought large changes to the German energy sector. The EEG introduced fixed feed-in-tariffs for renewables and forced grid operators to favor renewable energies (Löbbe & Hackbarth, 2017). The EEG was largely successful, as renewable energies saw great growth in the last two decades within

Germany. Wind energy, in particular, grew from a share in electricity production of 1.63 % in 2000 to a share of 20.2 % in 2021 (Ritchie & Roser, 2022). Consequently, the EGG has been adapted by several other countries (Laes et al., 2014).

Due to a larger share of renewables, the energy system structure has also changed. Liberalization of the German energy sector, similarly to France, accelerated in 1996 with the adaptation of an EU directive. In Germany, this culminated in 2005 with the *Energiewirtschaftsgesetz* (Energy Industry Act). The act set out that electricity generation, transmission, distribution, and retail are to be unbundled, leading to a highly competitive electricity market (Löbbe & Hackbarth, 2017). The German electricity market had been largely shared by four big companies: E.ON, RWE, EnBW, and Vattenfall (Kungl, 2014). In 2008, the big four generated 84% of all electricity. In 2020, their share had fallen to 65% (Bundesnetzagentur, 2021). This is because the latter only owns around 5% of all renewable energy plants (Werner & Scholtens, 2017; Wagner et al., 2021).

The German energy and electricity market, in contrast to the French one, relies heavily on renewables for its transition, and is more decentralized, in nature. Electricity is however more expensive, in the last semester of 2021, electricity prices in Germany reached a record, 0.3432 € per kwh, a price which exploded with the Ukrainian war (Eurostat, 2022).

5. Results

5.1 Data Analysis

In terms of policy count, 44 policies were kept for France and 78 for Germany. A higher number of policies were selected for Germany. It is, however, not the count of policies that is most interesting, but rather their content. Indeed, one particularly destructive policy would have more implications for the energy transition of Germany or France. In terms of temporal trends within the chosen scope of 2010-2022, differences can be noted. Germany has had several policies roll out consistently across the years, with some peaks. In the French context, a small uptick in policy roll-out concerning energy policies can be observed in the last three years, which comes after the national Climate Law of 2019. The data mirrors the present energy strategies of both countries. Germany has pursued quite an aggressive approach to their energy transition through the *Energiewende*, while France has found itself to be less pursuant in that regard.

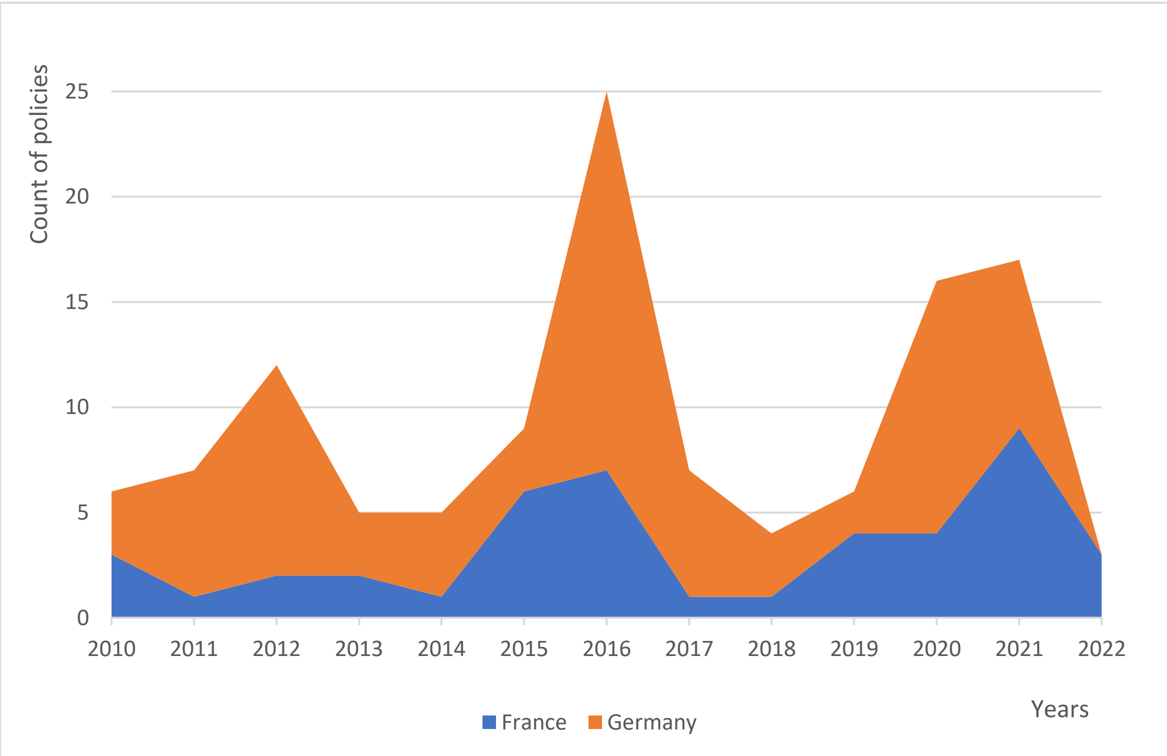

***Figure 4**. Count of selected policies for France and Germany between 2010-2022*

5.2 Policy mixes

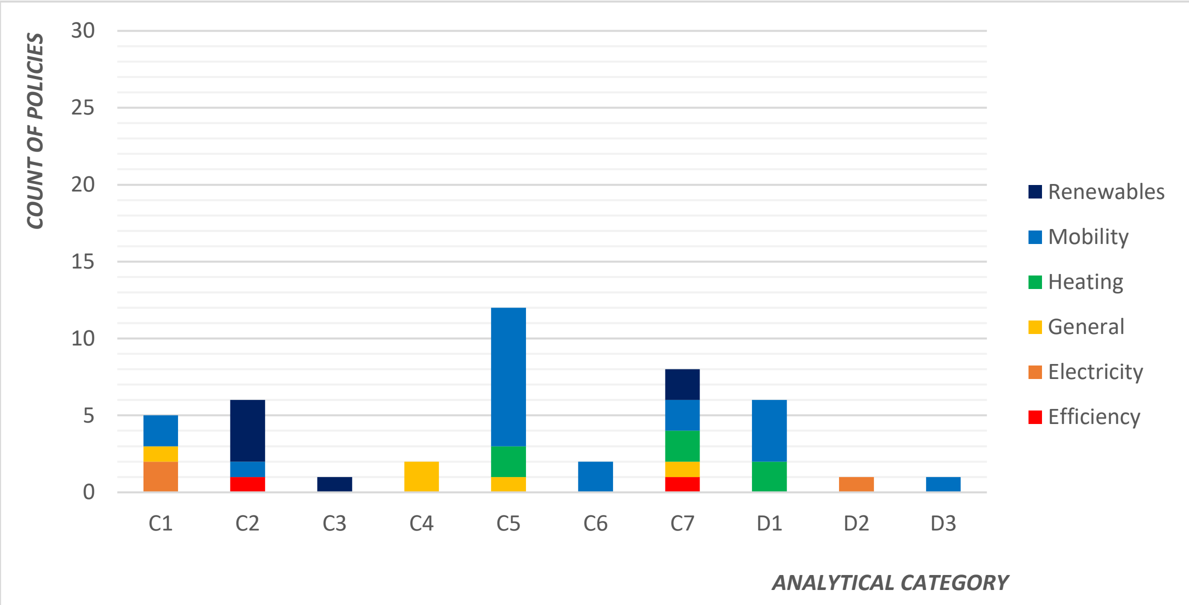

***Figure 5**. Partial energy policy mix of France between 2010 and 2022.*

All selected policies from the IEA database were assigned to a category based on the analytical framework of Kivimaa & Kern (2016). The D4 category is missing is from the figure, as no corresponding policy could be found.

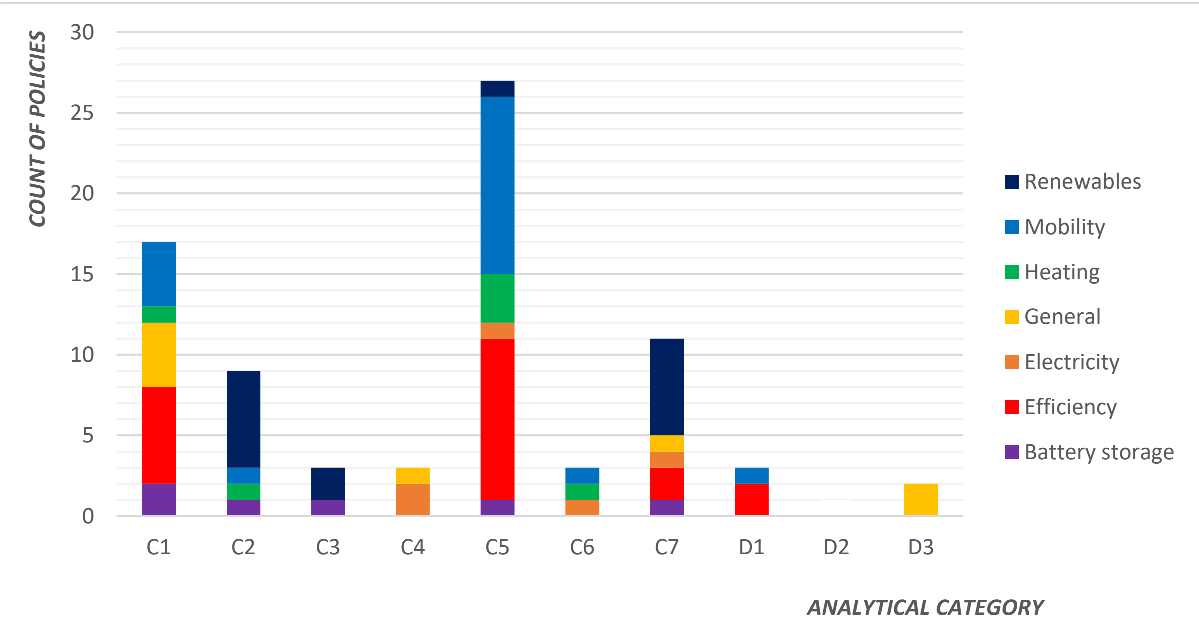

***Figure 6.** Partial energy policy mix of Germany between 2010 and 2022.*

All selected policies from the IEA database were assigned to a category based on the analytical framework of Kivimaa & Kern (2016). The D4 category is missing is from the figure, as no corresponding policy could be found.

5.2.1 Policy-mix of France

Of the selected destructive policies, quite a few relate to the mobility field, with obligations to build electric vehicles (EVs) charging infrastructures, in new parking lots, for example. This view is also supported by the fact that French policy, adopted an EU-regulation which seeks to ban fossil-fuel-based cars by 2040, weakening support for present dominant regime technologies. Another destructive policy is given by the forcing rule which forbids the installation of new oil heaters, which could push toward the adoption of heat pumps. To also be noted is the deployment of “Linky” smart electricity meters, which completely replaced the previous dumb electricity meters, pushing the French energy sector towards a more consumer-oriented regime (D2).

On the creative policy side, targeted sectors are not very mixed. Indeed, as France is mainly reliant on nuclear energy for its electricity needs, which is subject to lock-ins, French policies mainly try to limit emissions from fossil fuels, which in the French energy mix are mainly used in the transportation and heating sector. Deployment subsidies are therefore mainly relegated to those two sectors, as EVs, as well as heat pumps, are technologies that can contribute most to lowering French GHG emissions. This is also reflected in terms of the innovation policy mix (C1). Indeed, R&D developments are mostly relegated to the field of electric mobility, while general innovation funds and small electricity grid innovations, in particular settings, such as electricity production through gas, take a more minor role. Influencing Targets (C7), are, however, more diverse in terms of targeted sectors.

France is making tentative steps, in terms of market creation for renewable energies. offshore wind farm public tenders have been organized by the French state. One price-performance improvement has been implemented with an improved feed-in tariff for renewables implemented in 2016. No specific battery storage policies could be found.

5.2.2 Policy-mix of Germany

Germany has few destructive policies in place, but some have had and will have huge implications for the deployment of renewables. In 2011 it was decided that nuclear energy would be progressively abandoned, and in 2022, Germany decided it would fully decommission coal by 2038. This general policy to promote renewables is especially visible in influencing targets (C7). Since 2010, Germany has regularly set renewable share goals, which have been constantly improved. Other destructive policies, at D1, are softer, such as energy efficiency regulations for new houses or the obligation for public authorities to up their share of new vehicle purchases to be at least 20 percent of EVs. No policies impacting the energy regime have been found, under category D2. According to the energy strategy of Germany and its formation, the country has had a less locked-in regime, which translates into the fact that Germany has a diverse range of policies on the creative side. At C1, Research & Development was supported in all sectors and consistently across the years. This is also evidenced with C5, as deployment subsidies have been allocated to a diverse range of technologies.

Germany has for a long time supported the creation of markets for new technologies to break through, which are also often coupled with price-improvement mechanisms allowing for their growth. As an example, the country implemented a feed-in tariff for renewable energies, which is especially relevant for private solar installations. This market was supported through loans for solar and battery storage installations in 2016.

Under aspect C6, Germany also legitimizes new energy technologies by setting standards namely for electric car chargers and smart meters. Germany also encourages experimentation of entrepreneurs, especially in terms of smart electricity grid applications. The investments in the C4 category are however not repercussed by deployment subsidies. Finally, battery storage policies are present at all levels, which has been successful, considering Germany's present capacity of installed devices.

Generally, what comes out is that Germany has invested in a variety of technologies in a multitude of sectors, with a heavy focus on market formation.

5.2.3 Comparison of both policy mixes

Striking is the fact that in both countries, few destructive policies have been put in place. This observation was also supported by Kivimaa & Kern (2016) when analyzing the low-energy policy mixes of Finland and the UK. Additionally, for both countries, no policy belonging to D4, the replacement of key actors could be found. Destabilizing strategies are therefore rare in both energy policy mixes.

For both countries, resource mobilization strategies (C5) were the most common, in terms of the absolute number of policies. This is similar to observations made by Kivimaa & Kern (2011). In terms of differences in creative measures, Germany had proportionally far more knowledge of creative measures (C1) than France, with the former also being more diverse in the sectors it supports. France and Germany both used influencing target measures quite often for a variety of sectors.

Implications of the policy mixes vary. In general, the policy mixes reflect the needs of both respective countries as well as the respective level of their energy transition, and political cultures. France is more likely to use enforcing strategies. Indeed, the French energy market is more centralized, which allows for more top-bottom enforcing regulations, proportionally. This can be seen with the smart meter deployment which was enforced on the whole country, without real concertation. Comparatively, Germany decided to merely implement a standard for smart meters, and allow consumers to decide for themselves whether they wanted to adopt this technology. This is also seen with the enforcing policies of category D1. While France purely and simply banned the installation of new fuel oil boilers, Germany has not implemented such a policy, which bans pre-existing technologies.

This goes to show that Germany has a greater tendency to use market-based polices. On top of the feed-in tariff which is in place in both countries, Germany introduced a CO_2 price for the transport and heating sector in 2021 and has pursued such strategies in other sectors as well. In France, such mechanisms are much rarer. On one occasion, the French government put in place a market for companies to pursue energy-efficient measures through certificate trading. Other market-based mechanisms are however limited to renewables.

5.3 Policies and Digitalization

While the general policy mixes give us an indication as to how energy digitalization could implement itself in the general process of on-going energy transitions, some policies in both countries directly mention digitalizing measures. Seven of them have been selected for France and eleven for Germany.

5.3.1 Digitalizing policies in France

As could be expected, digitalization policies involving the French energy systems are quite limited and recent, with five out of the seven selected, having been acted after 2020. Most policies mention generic investments into digital technologies, with the Digital and Environmental Roadmap mentioning the linkages between 5G, artificial intelligence, and ecological transitions. Other smaller investments also appear, with the energy regulating agency in France, allowing the R&D of a smart electricity grid in relation to gas-powered electricity.

Also noteworthy is the fact that two French policy documents, see digitalization and environmental concerns as major policy drivers. In both documents, however, few synergies between both topics were made. In the recovery and resilience plan, published in 2021 to foster development during the Corona pandemic, two funds for respectively digitalizing measures and environmental measures were cast aside (France Relance, 2021). The only measure which received money from both funds was the aviation sector, to support the greening of the latter, by R&D funding specifically in terms of hydrogen-related innovations. Secondly the Digital and Environmental Roadmap mostly mentions the possible greening of digital technologies in terms of waste and their digital impact, but not in terms of possible synergies in the general energy sector (France Relance, 2021).

5.3.2 Digitalizing policies in Germany

Similarly to the French case, digitalization policies often remain vague as to their objective. During the Corona pandemic, the German government decided to fund through their recovery plan, two specific measures: *Digitalisation & Sector Coupling* and *Digitalisation & Energy Efficiency*. Both measures are investments guaranteed by the German State, but the goals of these measures are not clearly stated and merely allude to generic R&D investments (CDU, 2020). R&D investments for innovative technologies are also set out by the *Package for the Future.* Finally, between 2011 and 2014, four other policies gave funding for the R&D and the deployment of smart and efficient energy management system innovations.

Germany has also approved more drastic polices to account for the vision of a future digitalized energy system. The Act on the Further Development of the Electricity Market, acted in 2016, sets out rules for an electricity market 2.0, where the flexibility of demand-supply, coupled with storage solutions compete. This would constitute the first step towards a smarter grid. In a second step, the German government also approved, in 2018, an Electricity grid action plan, to build out connections to ensure the push towards a national interconnected grid. These measures can be considered promising advances.

5.4 Development of vital physical energy technologies

The need for digitalization is based on the deployment of certain types of physical energy technologies. The potential of the most important technologies according to Judson et al. (2020) are developed here.

5.4.1 Renewables & battery storage

France has relatively few policies that push for the implementation of renewables, considering its dependence on nuclear energy. For example, a law simplifying the consumption of one's own produced electricity through solar energy only came into place in 2016. The opposite is observed in Germany which has an extensive policy in place surrounding decentralized renewable energy consumption. This links to policies regarding storage technologies. According to the data, Germany has six different policies in place concerning storage capabilities, while France has none.

5.4.2 Heat pumps

In France, deployment subsidies for heat pumps are in place since 2021, while targets for the latter have been in place since 2016. Germany has a more diverse range of technologies it seeks to push in the heating sector, including modern heat fuel cells and the development of "4.0 heat systems". Heat pumps are however being newly favored. The German government has announced a new ambitious goal of installing half a million heat pumps annually by 2024 onwards (Wettengel 2022).

5.4.3 *Electric mobility*

In general, in both countries, policies seek to replace fossil-based cars through the alternative of EVs. Indeed, EVs are heavily pushed through numerous deployment subsidies and make up most policies in the mobility sector. France takes a more drastic approach than Germany in that regard by e.g the ban of fossil-powered cars by 2040. Such a policy could not be found in Germany. Furthermore, France also announced its will to create a law preparing for the deployment of automated cars. The French state also wants to push for the adoption of a law enshrining the right of access to plug for electric vehicles.

5.4.4 *Smart meter*

Finally, smart meters are where the deployment potential differences are starkest. As mentioned, France pursued a particularly destructive method by simply enforcing a nation-wide replacement of dumb electricity meters. In Germany, the solution was softer. The Act of the Digitalization of the Energy Transition merely stipulates standards for smart meters in terms of security and leaves the decision to adopt such technology to consumers.

6. Discussion

6.1 Present Implementation

For a digitalized energy system some technologies will be essential. Renewables and battery storage are part of the German energy regime and should continue to develop themselves, while in France, small steps have been made towards a wider integration of such technologies, as market opportunities for both have greatly increased.

As evidenced by the data, few destructive policies have been put in place in both countries. One could therefore assume that France and Germany count more on the general adoption of new technologies in the heating, mobility, and electricity sector, through market-based mechanisms. For both countries, developments of heat pumps and EVs look promising but are bound to the adoption of the consumers to become generalized technologies, which could take several years.

Digitalization strategies are however insufficient according to the data in both countries. While France tends to implement more controlling and destructive policies in terms of its energy transition, it does presently not have the need or capacity to transition to a digitalized grid, due to a small share of renewables, whereas the general electricity grid would not be ready for a full digital transformation. The implementation of the *Linky* smart electricity grid is therefore debatable and was mainly put in place to meet EU-wide targets in terms of smart meter implementation. It could also be envisioned as a mere cost-reductive measure by the company responsible for these counters, namely ENGIE.

Additionally, policy documents showcase that France tends to see digitalization and environmental concerns separately, with no application to its electricity grid, with exception of small-scale implementation of monitoring networks for gas transmissions.

In Germany, digitalization strategies are more developed but still lacking. While Germany has made efforts to allow for the entrepreneurial experimentation of smart grid solutions, these were for example not seen in terms of deployment efforts. Additionally, a target was set to allow for a national grid expansion plan, but considering the given needs for grid transformation, a one-time plan will likely be insufficient. Also, to note is the fact that, no real over-arching energy digitalization plan could be found. Nevertheless, Germany has made progressive steps towards a more digitalized energy system, which is concordant with its present energy regime.

6.2 Disruptive Potential

Present policy mixes of France and Germany are not allowing for the emergence of a digitalized smart grid as envisioned by the EU. Considering that energy digitalization is reliant on physical energy technologies, waiting for markets mechanism to push for deployment could make for a slow digitalization transition. The relative unwillingness of both countries to use destructive policy measures supports that energy digitalization is likely to be slow.

The switching costs of a smart grid also remains a question. In a digitalized smart grid, the necessity of transforming present electricity grids is a known problem, which requires huge investments. Germany has however only made small signs of progress in that regard.

Finally, an important function of a digitalized smart grid is supposed, but the benefits for consumers in terms of data management/protection and energy production capabilities are less obvious. Few policies for the support of such tools exist. In France, one own's production of energy has only recently been regulated. In Germany, such measures are more present but could benefit from informational campaigns, for example.

The digitalization of energy systems is arbored as a possibly disruptive and transformative process, which could manage to link sustainability and environmental concerns. However, governments seem to conceive energy policies in a siloed manner. Germany tends to regroup measures under the guise of efficiency, but lacks a global vision as to how its future energy grid should look like. With France, its locked-in regime entails that it mainly stipulates policies surrounding the sectors of heat efficiency and mobility, preventing the emergence of a global energy vision, which would support the emergence of a digitalized smart grid.

Considering these factors, it is more likely that digital tools in the energy transition will play an incremental role, in simple optimization and efficiency gains in the next years. For a wider transformation of energy systems to their digital potential, far-reaching policy measures will need to be taken. This also questions whether this vision is feasible in the first place and whether other energy strategies should be adopted, such as steps toward more sobriety.

The results are supported by a recent study of the EU, which found that to push for a digitalization of its energy systems, 584 billion euros, would need to be invested into grid development and transformations, with 110 billion euros specifically allocated to digitalization measures, to achieve the objectives set out by the *Action Plan on the digitalization of the energy sector* (Abnett, 2022). An ambitious feat to accomplish.

7. Conclusion

This paper sought to understand how energy digitalization could implement itself in on-going energy transitions, by using France and Germany as case studies. It was considered that in present energy regimes policies have a highly influencing role, due to the particularly stringent path dependency energy systems are subjected to. It particularly looked at the disruptive potential of energy digitalization.

The results showed that France and Germany policy mixes are presently not suited for a wider digital transformation of their respective energy systems. The policy mixes of France and Germany heavily support decarbonization measures, and policy mechanisms particularly favouring renewables are in place in both countries. Heat pumps and EVs, are both also supported by deployment subsidies in France and in Germany. Destructive policies are however few, which means that the generalisation of such technologies will be primarily dependent on market mechanisms and consumer adoption, which could take some time. On top of that, the collected data of both countries did not contain policies seeking to inform consumers about the possible application of digital technologies in regard to energy systems. One destructive measure pertaining to the implementation of smart meters in France was found. This policy has however a negligible role to play due to the very centralised nature of the French energy regime, which will likely not be overturned in the near future. A wider digital transformation is also prevented by the siloed manner in which energy policies are conceived, hindering cross-sector synergies. Finally, a digitalized, decarbonized, consumer-oriented smart grid necessitates an overhaul of present electricity grids. The question remains as to who would finance such switching costs.

Due to the incomplete nature of the collected data and the general outlook, these findings could be supplemented by an analysis which would look at policies of one single technology, in a more restricted manner. Nevertheless, this study provided first steps towards a better understanding of the potential of energy digitalization in the EU, which arbors dreams of a digitalized interconnected electricity grid, where consumers would actively participate.

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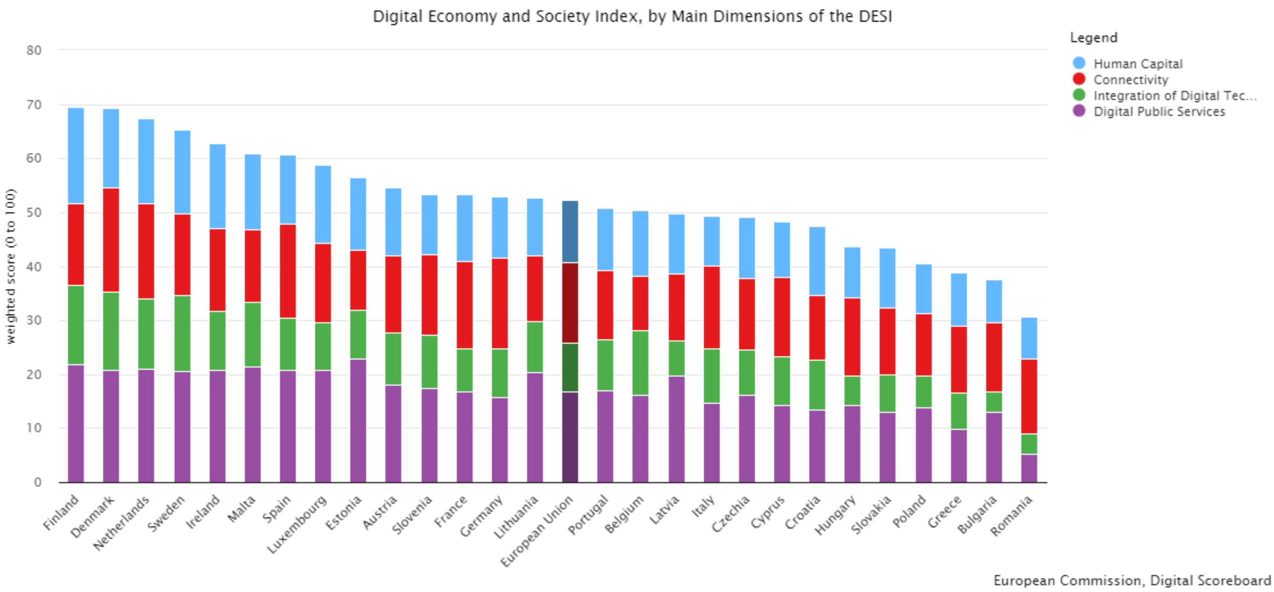
Appendices

Appendix I

Digital Economy and Society (DESI) index of the EU (European Commission, 2022)

The DESI index ranks EU countries according to their digital capabilities, infrastructures, human capital and public services. Created in 2014, yearly reports track the progress of Eu members. More informations on the index can be found here.



Appendix II

Policies taken from the IEA database for France

Code	Database	Policy Name	Type of policy	Year	Domain	Classification	Justification	Link	DIGITALISATION
1	IEA	**France 2030**	Tender	2022	Renewables	C2	Establishes offshore wind market	https://www.iea.org/policies/15025-france-2030-investment-plan-investment-in-renewable-energy-innovation	
2	IEA	**France 2030**	Investment	2022	Mobility	C5	Deployment funding	https://www.iea.org/policies/15027-france-2030-investment-plan-clean-transport-investment	
3	IEA	**Deliberation of the Energy Regulation Commission of 20 January 2022, approving Storengy's investment program for 2022**	Investment	2022	Electricity	C1	R & D funding to develop a monitoring system	https://www.iea.org/policies/15428-deliberation-of-the-energy-regulation-commission-of-20-january-2022-approving-storengys-investment-program-for-2022	
4	IEA	**Decree 2021-153 - establishing support to investments relating to rapid charging infrastructures for electric vehicles on major roads**	Subsidy	2021	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/14233-decree-2021-153-establishing-support-to-investments-relating-to-rapid-charging-infrastructures-for-electric-vehicles-on-major-roads	
5	IEA	**French Automotive Sector Support Plan**	Investment	2021	Mobility	C1	R & D funding	https://www.iea.org/policies/11466-automotive-sector-support-plan	
6	IEA	**Digital and Environmental Roadmap**	Strategic Plan	2021	General	C1	R & D funding	https://www.iea.org/policies/12910-digital-and-environment-roadmap	DIGITALISATION
7	IEA	**Electricty production thorugh renewables**	Aid Sheme	2021	Renewables	C2	Seeks to establish markets for these technologies	https://www.iea.org/policies/14108-electricity-production-through-renewables	
8	IEA	**Property tax exemption**	Tax Levy	2021	Heating	C5	Deployment is rendered easier by tax exemption	https://www.iea.org/policies/8729-property-tax-exemption	
9	IEA	**Recovery and resilience**	Investment	2021	Heating	C5	Heating pump Deployment is subvention	https://www.iea.org/policies/12488-recovery-and-resilience-plan	
10	IEA (extract)	**Recovery and resilience**	Investment	2021	Mobility	C5	General R&D for Deployment	https://www.iea.org/policies/12488-recovery-and-resilience-plan	DIGITALISATION
11	IEA (extract)	**Recovery and resilience**	Regulation	2021	Mobility	C6	Regulation to prepare for automated cars	https://www.iea.org/policies/12488-recovery-and-resilience-plan	DIGITALISATION
12	IEA (extract)	**Recovery and resilience**	Investment	2021	General	C5	Platform which seeks to push forward innovation in terms of energy transitions. Specifically mentions digitalisation, but only in relation to mobility	https://www.iea.org/policies/12488-recovery-and-resilience-plan	DIGITALISATION
13	IEA	**Auto industry - promoting demand for clean vehicles**	Investment	2020	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/3242-auto-industry-promoting-demand-for-clean-vehicles	
14	IEA	**Sustainable mobility package**	Subsidy	2020	Mobility	C5	Subsidy for electric mobility	https://www.iea.org/policies/8793-sustainable-mobility-package	
15	IEA	**Deliberations by the Energy Regulation Commission on the tariffs for natural gas transmission networks, LNG terminals and gas storage system**	Investment	2020	Electricity	C1	Investment for R&D surrounding smart grid technologies in relation to	https://www.iea.org/policies/15430-deliberations-by-the-energy-regulation-commission-on-the-tariffs-for-natural-gas-transmission-networks-lng-terminals-and-gas-storage-system	DIGITALISATION
16	IEA	**EU RRP / Energy Renovation of buildings/ Reforming thermal regulation for buildings**	Regulation	2020	Heating	D1	Forbidding of existing technology	https://www.iea.org/policies/7687-eu-rrp-energy-renovation-of-buildings-reforming-thermal-regulation-for-buildings	
17	IEA	**Framework Law on Mobility**	Strategic Plan	2019	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/8845-framework-law-on-mobility	
18	IEA (extract)	**Framework Law on Mobility**	Strategic Plan	2019	Mobility	C6	Seeks to establish a right to access to plug	https://www.iea.org/policies/8845-framework-law-on-mobility	
19	IEA	**LAW No. 2019-1428 on the Orientation of Mobility**	Regulation	2019	Mobility	D3	Bans in the future the sale of cars using fossil fuels	https://www.iea.org/policies/14791-law-no-2019-1428-on-the-orientation-of-mobility	
20	IEA (extract)	**LAW No. 2019-1428 on the Orientation of Mobility**	Targets	2019	Mobility	C7	Performance targets	https://www.iea.org/policies/14791-law-no-2019-1428-on-the-orientation-of-mobility	
21	IEA	**ELAN law on housing and decree 2019-771**	Regulation	2018	Renewables	C2	regulation for market formation	https://www.iea.org/policies/6561-elan-law-on-housing-and-decree-2019-771	
22	IEA	**Company Car Tax Benefits for EV and Hybrid Vehicles**	Tax Levy	2017	Mobility	C5	Improves price performance of EV's for Deployment	https://www.iea.org/policies/2883-company-car-tax-benefits-for-ev-and-hybrid-vehicles	
23	IEA	**Car rental and taxi fleet renewal**	regulation	2016	Mobility	D1	Forces switch to EV's	https://www.iea.org/policies/2851-car-rental-and-taxi-fleet-renewal	
24	IEA	**Central and Local Government Fleet Renewal Mandates**	subsidy, regulation	2016	Mobility	C5	Subsidy for Deployment	https://www.iea.org/policies/6674-central-and-local-government-fleet-renewal-mandates	
25	IEA	**Arrêté du 24 avril 2016 relatif aux objectifs de développement des énergies renouvelables)**	Target	2016	Heating	C7	Influencing Targets	https://www.iea.org/policies/6370-decree-of-24-of-april-2016-on-renewable-energy-developments-objectives-arrete-du-24-avril-2016-relatif-aux-objectifs-de-developpement-des-energies-renouvelables	
26	IEA (extract)	**Arrêté du 24 avril 2016 relatif aux objectifs de développement des énergies renouvelables)**	Target	2016	Renewables	C7	Influencing Targets	https://www.iea.org/policies/6370-decree-of-24-of-april-2016-on-renewable-energy-developments-objectives-arrete-du-24-avril-2016-relatif-aux-objectifs-de-developpement-des-energies-renouvelables	
27	IEA	**EV Infrastructure Charging Program (ADVENIR)**	Investment	2016	Efficiency	C2	Market for certificates, financing EV's	https://www.iea.org/policies/2716-ev-infrastructure-charging-program-advenir	
28	IEA	**Low Emissions Zone (Crit'Air)**	Regulation	2016	Mobility	D1	Forces switch to more energy efficient cars or EV's. While it also establishes a new market so to say, in terms of digitalization, this market has more of a restrictive quality which pushes towards the latter.	https://www.iea.org/policies/3136-low-emissions-zone-critair	
29	IEA	**Support scheme for electricity produced from renewable energy sources**	Feed-in-Tariff	2016	Renewables	C3	Establishes a market for renewables	https://www.iea.org/policies/6126-support-scheme-for-electricity-produced-from-renewable-energy-sources-loi-n0-2015-992-du-17-aout-2015-relative-a-la-transition-energetique-pour-la-croissance-verte	
30	IEA	**Building code - EV charging**	Regulation	2015	Mobility	D1	Incumbent building businesses will have to adapt	https://www.iea.org/policies/1068-building-code-ev-charging	
31	IEA	**Demonstration Fund "Vehicle and Transport of the Future" implemented by the Agency for Environment and Energy Management (ADEME)**	Investment	2015	Mobility	C1	R&D Fund	https://www.iea.org/policies/2719-demonstration-fund-vehicle-and-transport-of-the-future-implemented-by-the-agency-for-environment-and-energy-management-ademe	
32	IEA	**Law on Energy Transition for Green Growth (LTECV)**	Target	2015	Renewables	C7	Influencing Targets	https://www.iea.org/policies/8737-law-on-energy-transition-for-green-growth-ltecv	
33	IEA (extract)	**Law on Energy Transition for Green Growth (LTECV)**	Target	2015	Mobility	C7	Influencing Targets	https://www.iea.org/policies/8737-law-on-energy-transition-for-green-growth-ltecv	
34	IEA (extract)	**Law on Energy Transition for Green Growth (LTECV)**	Regulation	2015	Electricity	D2	This policy had huge implications, in France, as consumers could not refuse the installation of the linky Smart meter. It changed the regime, to be more consumer-oriented.	https://www.iea.org/policies/8737-law-on-energy-transition-for-green-growth-ltecv	DIGITALISATION
35	IEA	**Tax Credit EV**	Tax Credit	2015	Mobility	C5	Subsidy for Deployment	https://www.iea.org/policies/3277-tax-credit	
36	IEA	**Tax exemption for the use of public space**	Tax exemption	2014	Mobility	C2	Tax exemption to establish EV charging market	https://www.iea.org/policies/3279-tax-exemption-for-the-use-of-public-space	
37	IEA	**BPI FRANCE**	Investment	2013	General	C4	Advice for entrepreneurs in terms of funding	https://www.iea.org/policies/136-bpi-france-innovation-for-smes-support-for-rd	
38	IEA	**Energy efficiency target declared by France under the EU Directive (2012/27/EU)**	Target	2013	Efficiency	C7	Influencing Targets	https://www.iea.org/policies/237-energy-efficiency-target-declared-by-france-under-the-eu-directive-201227eu	
39	IEA	**Mandate charging infrastructure parking garage**	Regulation	2012	Mobility	D1	Incumbent building businesses will have to adapt	https://www.iea.org/policies/8537-mandate-charging-infrastructure-parking-garage	
40	IEA	**Thermal Regulation**	Regulation	2012	Heating	D1	Incumbent building businesses will have to adapt	https://www.iea.org/policies/2513-thermal-regulation-2012	
41	IEA	**Offshore wind tendering mechanism**	Tender	2011	Renewables	C2	Establishes offshore wind market	https://www.iea.org/policies/5144-offshore-wind-tendering-mechanism	
42	IEA	**Green innovation funding: the French programme of Investments for the future**	Investment	2010	General	C4	Seeks to establish demonstrations for funded projects;	https://www.iea.org/policies/552-green-innovation-funding-the-french-programme-of-investments-for-the-future	DIGITALISATION
43	IEA	**National Renewable Energy Action Plan (NREAP)**	Target	2010	General	C7	Influencing targets	https://www.iea.org/policies/1038-national-renewable-energy-action-plan-nreap	
44	IEA	**National commitment to the environment - Grenelle 2**	Regulation	2010	Heating	C7	Influencing targets	https://www.iea.org/policies/408-national-commitment-to-the-environment-grenelle-2	

Appendix III

Policies taken from the IEA database for Germany

Code	Database	Policy Name	Type of policy	Year	Domain	Classification	Justification	Link	Mention Digitalisation directly
45	IEA	***Act to Reduce and End Coal-Fired Power Generation***	Regulation	2021	General	D3	Reduced support for coal	https://www.iea.org/policies/13337-act-to-reduce-and-end-coal-fired-power-generation	
46	IEA	***CO2 price for transport and heating***	Tax (carbon)	2021	Heating	C2	Establishes carbon market for the heating and transport sector	https://www.iea.org/policies/11632-co2-price-for-transport-and-heating	
47	IEA (extract)	***CO2 price for transport and heating***	Tax (Carbon)	2021	Mobility	C2	Establishes carbon market for the heating and transport sector	https://www.iea.org/policies/11632-co2-price-for-transport-and-heating	
48	IEA	***Federal Climate Change Act 2021***	Regulation	2021	Renewables	C7	Influencing Targets	https://www.iea.org/policies/13518-federal-climate-change-act-2021	
49	IEA	***Federal Subsidy for Efficient Buildings (BEG) by KfW***	Subsidy	2021	Efficiency	C5	Low interest loans	https://www.iea.org/policies/14957-federal-subsidy-for-efficient-buildings-beg-by-kfw	
50	IEA	***German Development and Resilience Plan (DARP)***	Investment	2021	General	C1	General R&D	https://www.iea.org/policies/13983-german-development-and-resilience-plan-darp	
51	IEA	***Germany's Renewables Energy Act***	Regulation	2021	Renewables	C7	Influencing Targets	https://www.iea.org/policies/12392-germanys-renewables-energy-act	
52	IEA	***Sustainable battery cell production***	Investment	2021	Battery storage	C1	General R&D	https://www.iea.org/policies/14199-sustainable-battery-cell-production	
53	IEA	***Digitalisation and sector coupling***	Investment	2020	Electricity	C4	R&D funding for experimentation	https://www.iea.org/policies/11550-digitalisation-and-sector-coupling	DIGITALISATION
54	IEA	***Digitalisation and energy efficiency***	Investment	2020	Efficiency	C1	General R&D	https://www.iea.org/policies/11798-digitalisation-to-improve-energy-efficiency	DIGITALISATION
55	IEA	***Offshore Wind Energy Act (Amendment) - Increase of Expansion Target***	Target	2020	Renewables	C7	Influencing Targets	https://www.iea.org/policies/11508-offshore-wind-energy-act-amendment-increase-of-expansion-target	
56	IEA	***Package for the future***	Investment	2020	General	C1	R&D	https://www.iea.org/policies/13465-package-for-the-future	DIGITALISATION
57	IEA	***Zukunftpaket mobility***	Subsidy	2020	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/13481-package-for-the-future-mobility	
58	IEA (extract)	***Zukunftpaket mobility***	Information	2020	Mobility	C5	Educational strategy	https://www.iea.org/policies/13481-package-for-the-future-mobility	
59	IEA (extract)	***Zukunftpaket mobility***	Investment	2020	Mobility	C1	General R&D	https://www.iea.org/policies/13481-package-for-the-future-mobility	
60	IEA	***Zukunftpaket renewables***	Regulation	2020	Renewables	C3	Improves market price of solar	https://www.iea.org/policies/13506-package-for-the-future-expansion-of-renewable-energies	
61	IEA	***Renewed support for the automotive sector***	Investment	2020	Mobility	C1	R&D fund	https://www.iea.org/policies/13974-renewed-support-for-the-automotive-sector	
62	IEA	***Sustainable Transport - Bus and truck fleet modernisation programme***	Investment	2020	Mobility	C5	Deployment Investment	https://www.iea.org/policies/11555-sustainable-transport-bus-and-truck-fleet-modernisation-programme	
63	IEA	***Sustainable Transport- Charging infrastructure***	Investment	2020	Mobility	C5	Deployment Investment	https://www.iea.org/policies/11554-sustainable-transport-charging-station-infrastructure	
64	IEA(extract)	***Sustainable Transport- Charging infrastructure***	Investment	2020	Battery Storage	C5	Deployment Investment	https://www.iea.org/policies/11554-sustainable-transport-charging-station-infrastructure	
65	IEA	***Federal funding for energy efficiency in the economy - Funding Competition***	Tender	2019	Efficiency	C1	R&D funding	https://www.iea.org/policies/7714-federal-funding-for-energy-efficiency-in-the-economy-funding-competition	
66	IEA	***Project ELBE (incentive programme for EV charging infrastructure)***	Investment	2019	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/8540-project-elbe-incentive-programme-for-ev-charging-infrastructure	
67	IEA	***Bus purchase support***	Investment	2018	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/2848-bus-purchase-support	
68	IEA	***Federal funding for energy efficiency in the economy - Grant and Loan***	Investment	2018	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/7713-federal-funding-for-energy-efficiency-in-the-economy-grant-and-loan	
69	IEA	***Aktionsplan Stromnetz***	Strategic Plan	2018	Electricity	C7	Strategic Plan	https://www.iea.org/policies/6524-the-electricity-grid-action-plan	DIGITALISATION
70	IEA	***2017 Amendment of the Renewable Energy Sources Act (EEG 2017)***	Regulation	2017	Renewables	C2	Change in market formation of renewables	https://www.iea.org/policies/6125-2017-amendment-of-the-renewable-energy-sources-act-eeg-2017	
71	IEA	***Act on the Digitisation of the Energy Transition***	Regulation	2017	Electricity	C6	Legitimates the use of smart meters	https://www.iea.org/policies/6523-act-on-the-digitisation-of-the-energy-transition	DIGITALISATION
72	IEA	***Funding programme for "Heat Network systems 4.0"***	Investment	2017	Heating	C5	R&D Funding for Deployment and transformation	https://www.iea.org/policies/7711-funding-programme-for-heat-network-systems-40	
73	IEA	***Reduced electricity tax for electric buses***	Tax levy	2017	Mobility	C5	Deployment Subsidy	https://www.iea.org/policies/3221-reduced-electricity-tax-for-electric-buses	
74	IEA	***Landlord-to-tenant electricity: The energy transition heads into homes***	Subsidy	2017	Renewables	C5	Deployment subsidy	https://www.iea.org/policies/6527-the-landlord-to-tet-electricity-act-2017	
75	IEA	***The Offshore Wind Energy Act (WindSeeG)***	Regulation	2017	Renewables	C2	Market formation of offshore	https://www.iea.org/policies/6526-the-offshore-wind-energy-act-windseeg	
76	IEA	***Act on the Further Development of the Electricity Market***	Regulation	2016	Renewables	C2	Market formation of electricity market 2.0	https://www.iea.org/policies/6521-act-on-the-further-development-of-the-electricity-market	DIGITALISATION
77	IEA (extract)	***Act on the Further Development of the Electricity Market***	Regulation	2016	Battery Storage	C2	Market formation of electricity market 2.0	https://www.iea.org/policies/6521-act-on-the-further-development-of-the-electricity-market	DIGITALISATION
78	IEA	***Charging support plan***	Investment	2016	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/2862-charging-support-plan	
79	IEA	***Electric Vehicle (EV) 10-year circulation tax exemption***	Tax levy	2016	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/2865-electric-vehicle-ev-10-year-circulation-tax-exemption	
80	IEA	***Energy Efficiency Incentive Programme***	Investment	2016	Heating	C5	Deployment subsidy	https://www.iea.org/policies/1928-energy-efficiency-incentive-programme	
81	IEA	***Energy consulting for non-residential buildings of municipalities and NGOs (BAFA)***	Payment	2016	Heating	C6	Support from government for change in energy efficiency of municipalities	https://www.iea.org/policies/760-energy-consulting-for-non-residential-buildings-of-municipalities-and-ngos-bafa	
82	IEA	***Energy tax relief for highly efficient plants for the combined generation of power***	Tax levy	2016	Heating	C5	Deployment subsidy (Before C2, which was taken away)	https://www.iea.org/policies/2618-energy-tax-relief-for-highly-efficient-plants-for-the-combined-generation-of-power-and-heat	
83	IEA	***Government fleet mandatory PEV***	Regulation	2016	Mobility	D1	Control policies	https://www.iea.org/policies/3004-government-fleet-mandatory-pev	
84	IEA	***Heating system optimization***	Subsidies	2016	Heating	C5	Deployment subsidy	https://www.iea.org/policies/2624-heating-system-optimization	
85	IEA	***Income tax law***	Tax levy	2016	Mobility	C5	Resource mobilisation	https://www.iea.org/policies/3103-income-tax-law	
86	IEA	***Ladesäulenverordnung (LSV) - Charging Station Ordinance***	Regulation	2016	Mobility	C6	Standard for charging stations	https://www.iea.org/policies/3121-ladesaulenverordnung-lsv-charging-station-ordinance	
87	IEA	***Pilot program 'Einsparzaehler'***	Investment	2016	Electricity	C4	Incentive for experimentation of novel ideas	https://www.iea.org/policies/2218-pilot-program-einsparzaehler	DIGITALISATION
88	IEA	***Programme to Promote Investment in Highly Efficient Horizontal Technologies***	Investment	2016	Efficiency	C1	Knowledge Diffusion for industry	https://www.iea.org/policies/147-programme-to-promote-investment-in-highly-efficient-horizontal-technologies	
89	IEA	***Promotion of exemplar climate mitigation projects by municipalities***	Investment	2016	General	C4	Seeks to push for experimentation by municipalities	https://www.iea.org/policies/7712-promotion-of-exemplar-climate-mitigation-projects-by-municipalities	
90	IEA	***STEP up! Pilot program***	Funding	2016	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/8517-step-up-pilot-program	
91	IEA	***Subsidy for solar PV with storage installations (Programm zur Förderung von PV-***	Investment	2016	Renewables	C3	Seek to improve the cost of battery storage and solar PV installations	https://www.iea.org/policies/5971-subsidy-for-solar-pv-with-storage-installations-programm-zur-forderung-von-pv-batteriespeichern	
92	IEA (extract)	***Subsidy for solar PV with storage installations (Programm zur Förderung von PV-***	Investment	2016	Battery storage	C3	Seek to improve the cost of battery storage and solar PV installations	https://www.iea.org/policies/5971-subsidy-for-solar-pv-with-storage-installations-programm-zur-forderung-von-pv-batteriespeichern	
93	IEA	***Umweltbonus***	Tax levy	2016	Mobility	C5	Deployment subsidy	https://www.iea.org/policies/3294-umweltbonus-environmental-bonus	
94	IEA	***Compulsory energy efficiency audits in large companies***	Regulation	2015	Efficiency	D1	Control through audits	https://www.iea.org/policies/1723-compulsory-energy-efficiency-audits-in-large-companies	
95	IEA	***Ground-mounted PV Auction Ordice***	Regulation	2015	Renewables	C2	Creates market	https://www.iea.org/policies/5950-ground-mounted-pv-auction-ordice	
96	IEA	***KfW Energy Efficiency Programme: Energy-efficient construction and retrofitting***	Payment	2015	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/220-kfw-energy-efficiency-programme-energy-efficient-construction-and-retrofitting	
97	IEA	***2014 Amendment of the Renewable Energy Sources Act (EEG 2014)***	Regulation	2014	Renewables	C7	Influencing Targets	https://www.iea.org/policies/5734-2014-amendment-of-the-renewable-energy-sources-act-eeg-2014	
98	IEA	***3rd National Energy Efficiency Action Plan (NEEAP)***	Strategic Plan	2014	Efficiency	C7	Influencing Targets	https://www.iea.org/policies/1282-3rd-national-energy-efficiency-action-plan-neeap	
99	IEA	***Energy Conservation Regulations (EnEV) 2014***	Regulation	2014	Efficiency	D1	Controls targets	https://www.iea.org/policies/7641-energy-conservation-regulations-enev-2014	
100	IEA	***Energy and Electricity Tax cap***	Tax levy	2014	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/56-energy-and-electricity-tax-cap	DIGITALISATION
101	IEA	***KfW Special Fund for Energy Efficiency in SMEs***	Regulation	2013	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/289-kfw-special-fund-for-energy-efficiency-in-smes	
102	IEA	***Support of Energy Management Systems***	Regulation	2013	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/2266-support-of-energy-management-systems	DIGITALISATION
103	IEA	***Support of energy-efficient and climate-friendly production processes***	Payment	2013	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/872-support-of-energy-efficient-and-climate-friendly-production-processes	
104	IEA	***2012 Amendment of the Renewable Energy Sources Act (EEG 2012)***	Regulation	2012	Renewables	C2	Establishing new market through feed-in-tariff	https://www.iea.org/policies/5117-2012-amendment-of-the-renewable-energy-sources-act-eeg-2012	
105	IEA	***CHP Agreements with Industry***	Agreement	2012	Efficiency	C7	Voluntary Agreement	https://www.iea.org/policies/474-chp-agreements-with-industry	
106	IEA	***Electric mobility showcase Program***	Investment	2012	Mobility	C1	R&D Funding	https://www.iea.org/policies/6921-electric-mobility-showcase-program	
107	IEA (extract)	***Electric mobility showcase Program***	Investment	2012	Battery Storage	C1	R&D funding	https://www.iea.org/policies/6921-electric-mobility-showcase-program	
108	IEA	***Electricity Saving Initiative***	Information	2012	Efficiency	C1	Knowledge Diffusion for private households	https://www.iea.org/policies/271-electricity-saving-initiative	
109	IEA	***Energy Provisioning***	Investment	2012	Electricity	C5	Low interest loans	https://www.iea.org/policies/1440-energy-provisioning	
110	IEA	***Energy checks for private households***	Subsidy	2012	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/761-energy-checks-for-private-households	
111	IEA	***Financial support for investments in cross sectional technology***	Investment	2012	Efficiency	C5	Deployment subsidy	https://www.iea.org/policies/509-financial-support-for-investments-in-cross-sectional-technology	
112	IEA	***R&D programme for battery electric mobility "Show Cases Electric Mobility"***	Investment	2012	Mobility	C1	Showcasing platforms	https://www.iea.org/policies/938-rd-programme-for-battery-electric-mobility-show-cases-electric-mobility	
113	IEA	***SME Initiative energy transition and climate protection***	Regulation	2012	Efficiency	C1	Knowledge Diffusion for industry	https://www.iea.org/policies/823-sme-initiative-energy-transition-and-climate-protection	
114	IEA	***Energy Efficiency Fund***	Investment	2011	Efficiency	C1	R&D funding	https://www.iea.org/policies/2623-energy-efficiency-fund	DIGITALISATION
115	IEA	***KfW Programme Offshore Wind Energy***	Investment	2011	Renewables	C2	Establishes market for offshore wind farms	https://www.iea.org/policies/5134-kfw-programme-offshore-wind-energy	
116	IEA	***Law on Energy and Climate Fund***	Regulation	2011	General	C1	Promotion of technologies	https://www.iea.org/policies/5119-law-on-energy-and-climate-fund	
117	IEA (extract)	***Law on Energy and Climate Fund***	Regulation	2011	General	D3	Reduced support of nuclear	https://www.iea.org/policies/5119-law-on-energy-and-climate-fund	
118	IEA	***Sixth Energy Research Programme***	Strategic Plan	2011	Renewables	C7	Strategic vision	https://www.iea.org/policies/5118-sixth-energy-research-programme	
119	IEA (extract)	***Sixth Energy Research Programme***	Strategic Plan	2011	Battery Storage	C7	Strategic Vision	https://www.iea.org/policies/5118-sixth-energy-research-programme	
120	IEA	***Energy Concept***	Strategic Plan	2010	General	C7	Influencing Strategic Plan	https://www.iea.org/policies/106-energy-concept	
121	IEA	***Energy and Climate Act, 2010***	Investment	2010	General	C1	General R&D	https://www.iea.org/policies/2054-energy-and-climate-act-2010	
122	IEA	***National Energy Action Plan (NREAP)***	Target	2010	Renewables	C7	Influencing Targets	https://www.iea.org/policies/5411-national-energy-action-plan-nreap	