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Global trends in the political economy of smart grids

A tailored perspective on 'smart' for grids in transition

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Abstract: The global transition towards sustainable, secure, and affordable electricity supply is driving changes in the consumption, production, and transportation of electricity. This paper shows the different policy aims that are promoted with smart grids in Europe, the United States, and China. In all cases, the developments are motivated by the possible improvements in reliability and affordability yielded by smart grids, while sustainability of the electricity sector is not a central motivation.

Keywords: electricity, regulation, innovation, policy, smart systems
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1 Introduction

The global transition towards sustainable, secure, and affordable electricity supply is driving changes in the consumption, production, and transportation of electricity. In the past decade there has been a dash for 'smart' in power systems, resulting in a consensus that a 'smart grid' will pave the way to decarbonization, reliability, and (economic) efficiency in the electricity sector. On the basis of the terminology alone, smart grids have received a lot of support in government policy for the theoretical benefits implementation might bring.

Smart grids can be defined as electricity networks that enable two-way communication and power exchange between electricity consumers and producers, utilizing information and communication technology (ICT) to respond and manage demand, and ensure safe and secure electricity distribution (DOE 2006; Hall and Foxon 2014). A smart grid can support the reliability of the grid with the penetration of distributed generation and electric vehicles (EVs), and can deliver possibilities for real-time pricing that incentivizes demand response from consumers. Demand response refers to the possibility that consumers are 'responding' with their electricity demand either to changes in price or to specific incentive payments that induce lower electricity use at times of high market prices or when grid reliability is jeopardized (DOE 2006). Furthermore, smart metering can enable monitoring possibilities for both utilities and end-users to target energy efficiency and improved insights into network usage for the medium (MV) and low voltage (LV) electricity grids.

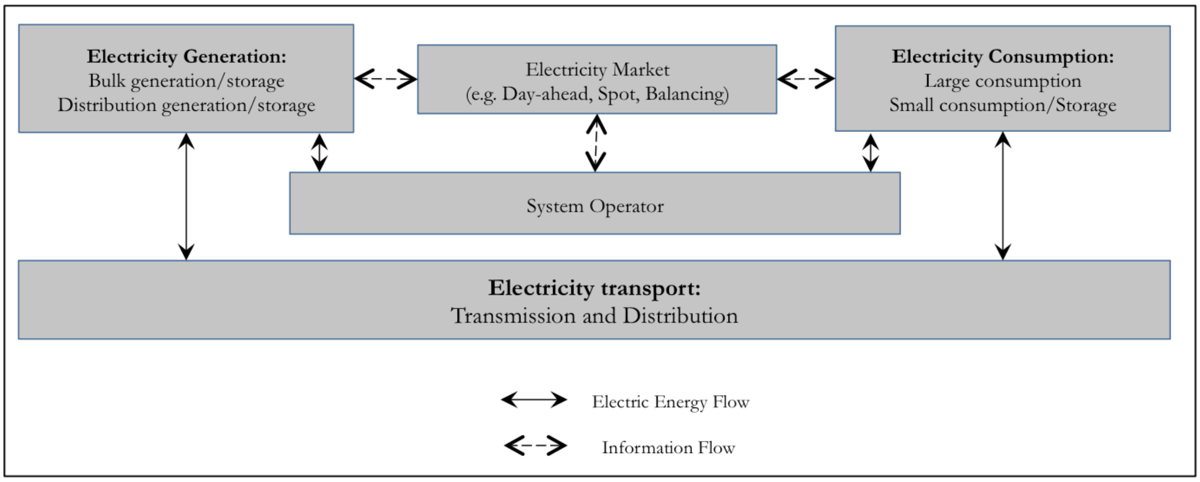
However, the smart grid concept is both broad and vague, leaving much room for speculation and interpretation by (inter)national and local authorities as well as the major stakeholders involved. This uncertainty allows actors to adopt a strategic position, but not to systematically favour the emergence of a structure and shared vision for a smart grid (Tricoire 2015). Within the subjectivity of the term (nobody would support a 'dumb grid'), the assumption exists that trade-offs between sustainability, affordability, and security of supply would be reduced with the transition towards a smart grid. It can be observed that the political economic context influences the motives for investing or not investing in smart grids. Nonetheless, not each investment necessarily contributes to the sustainability and affordability objectives from a greater social perspective. The conflicts between different policy objectives and the interests of the actors involved present an interesting point for further research. In this paper, the authors clarify which (set of) goal(s) are emphasized by smart grids in the United States (US), Europe, and China according to industry structure, regulatory context, and the power of energy policy.

2 The history of the use of 'smart grid' terminology

The functionalities of the smart grid are not recently discovered concepts. F.C. Schweppe and collaborators previously described these functions in a report called 'Homeostatic Control: The Utility/Customer Marketplace for Electric Power' (Schweppe et al. 1981). In this report, Schweppe et al. referred to homeostatic control as a way of maintaining internal equilibrium between electricity supply and demand with the use of economic signalling and information and communication technology. In order to reach such a level of homeostatic control, two important aspects are named as pre-conditions by Schweppe et al. (1981): firstly, the existence of *feedback between customer and utility* and, secondly, *customer independence*. Those two conditions are revolutionary in the power industry, where traditionally the customer receives no feedback on consumption behaviour and is traditionally perceived to be entirely dependent on the utility for electricity production, transportation, and delivery. Even though the report presents a very distinctive approach to the power system and its transactions, it shows that homeostatic control is not revolutionary in essence, but rather evolutionary due to the fact that it builds on advances in the information technology (IT) industry as well as on experience in customer load management, and combines those together.

Conceptually, the 1981 report presents a picture where a central marketplace controller is an intermediary platform for local and central system managements (see Figure 1). In order to manage the customer load, Schweppe et al. describe two forms of load management: direct and indirect control. Direct loads are ways in which the utility can directly manage electrical appliances by switching devices on or off. In contrast, indirect methods are economic incentives (for example a dynamic rate) that can provide incentives for the customer to consume electricity at specific times.

Figure 1: An early presentation of 'the innovative energy market place'



Source: Adjusted by the authors from Schweppe et al. (1981).

However, the term 'smart grid' itself was not used until 2005. In that year a report from the Institute of Electrical and Electronics Engineers (IEEE) was published, named 'Toward a Smart Grid: Power Delivery for the 21st Century' (Amin and Wollenberg 2005). In this report the electric grid was likened to a F15 aircraft with 'self-healing' possibilities in case of emergency, similar to the homeostatic description by Schweppe. In this colourful metaphor, the F15 aircraft is able to continue flying even after losing one wing due to fault detection and automation. This use of detection and automation was suggested as a possible way for electricity systems to improve transmission grid operations.

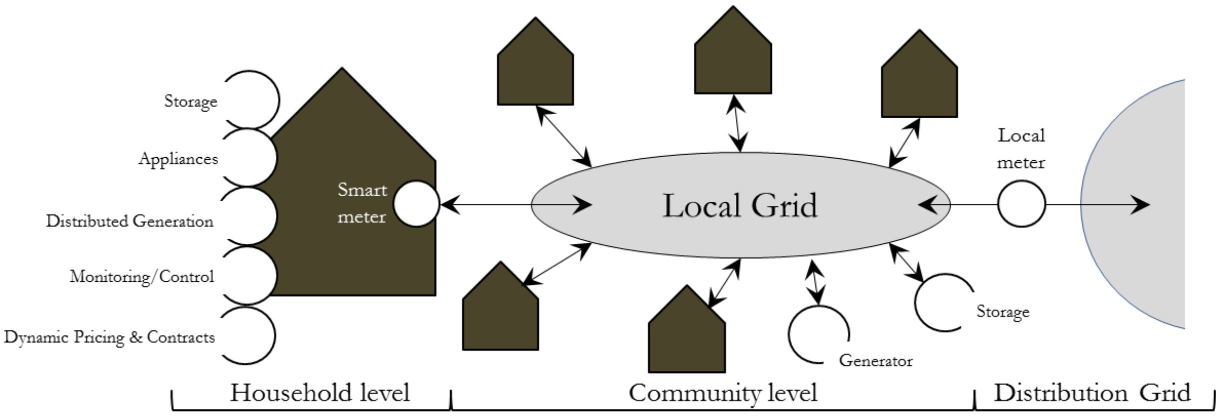
2.1 Defining smart grids

Technically speaking, it is not straightforward to define whether a grid is 'smart' or not 'smart'. Most systems, at least at the high voltage levels, have sensor and control systems in place in order to sustain reliability of supply with supervisory control and data acquisition systems (SCADA). However, distribution grids have traditionally been managed in a passive manner and therefore smart grids generally refer to new developments on the distribution side. Aspects of smart grids that can represent such developments are: 1) the installation of physical 'smart devices', and 2) the (real-time) operational management of those devices.

The smart meter is frequently seen as a prerequisite for smart grids. This digital meter enables end-user monitoring and is different from traditional electricity meters in that it can digitally measure consumption and production in short time intervals of typically 15 minutes.[1] It is important to note that a stand-alone smart meter does not possess the function of wireless communication, but this can be enabled with an additional wireless connection. This consumption data can be communicated to different actors. For example, it can be communicated to the consumers themselves who can then adjust their consumption based on this information. Usage data along with price signals are the key components of the 'homeostatic feedback' Schweppe envisioned and are central to any smart grid. Furthermore, this data can be of interest to the utility, the distribution service operator (DSO), retailer, and/or aggregator for billing purposes and evaluation of provided demand response. In this paper we remain focused on the electricity sector; however, we do acknowledge that IT networks and data management are also important matters for smart grid developments.

In addition to the smart meter, there are other devices that enable insight for the consumer and provide automated feedback on signals through, for example, in-home displays and in-home automation. **Distributed energy resources** (DER) are different types of units that enable local production, alternative consumption units, and/or storage. Examples of distributed generation (DG) units are solar photovoltaics (PV) and combined heat and power (CHP). **Battery storage** can provide important value as those units can increase self-consumption from electricity generation, reduce peak consumption, reduce system-wide generation costs, losses, and network congestions, and reduce costs for network expansions. **Electric vehicles (EVs)** can also be part of a smart grid. EVs can provide flexibility to the grid, when required, and can act as a storage unit for generated electricity.

Figure 2: Smart appliance categories



Source: Adapted and adjusted by the authors from Geelen et al. (2013).

2.2 Real-time management and control

The distributed energy resources and smart meters do not automatically operate efficiently after installation. The installation of such devices becomes profitable when combined with contracts for variable pricing, direct control, and automation (Faruqui et al. 2010; Aghaei & Alizadeh 2013; Geelen et al. 2013). The interactions of such devices can be called demand side flexibility or demand response. Demand response refers to the activity that the electricity demand is able to

[1] *Prosumption* refers to the possibility of an electricity consumer both consuming and producing electricity. This could be the case, for example, if the electricity consumer owns a solar photovoltaics panel.

‘respond’ to triggers like prices or direct control. There are multiple purposes for which the operation of smart devices can be optimized: economic, environmental, and network purposes for example (Conchado et al. 2011). The possibility of flexibility management is seen as one of the major added values of the smart grid (Faruqui et al. 2010). Technically, an electricity flexibility service can be defined *as a power adjustment sustained at a given moment for a given duration from a specific location* within the network. DER e.g. EVs, CHP units, electric water heaters, and storage units are potential providers of flexibility services (Eid et al. 2016).

There are other theoretical concepts, in addition to the smart grid, that describe innovation in electricity systems. All of these concepts require the integration of IT communication for real-time interactions between consumption, production, and storage. Examples include the micro grid, virtual power plant, and energy hubs.

2.3 The possible change of actor roles and functions

Traditionally, the transmission system operator (TSO) manages the balance of supply and demand of a national electricity system and uses ICT to sustain the voltage and frequency level (e.g. 50 Hz in Europe), without conflicting with transmission network constraints. As described earlier, the smart grid concept allows for real-time management not only at the transmission but also at the distribution level of the grid. Due to the fact that this functionality did not exist before, the questions remain which actor(s) should be responsible for the management of this flexibility and how should this be coordinated? Examples for these decentralized concepts of electricity system management have been presented by others (NREL 2004; Ruester et al. 2013).

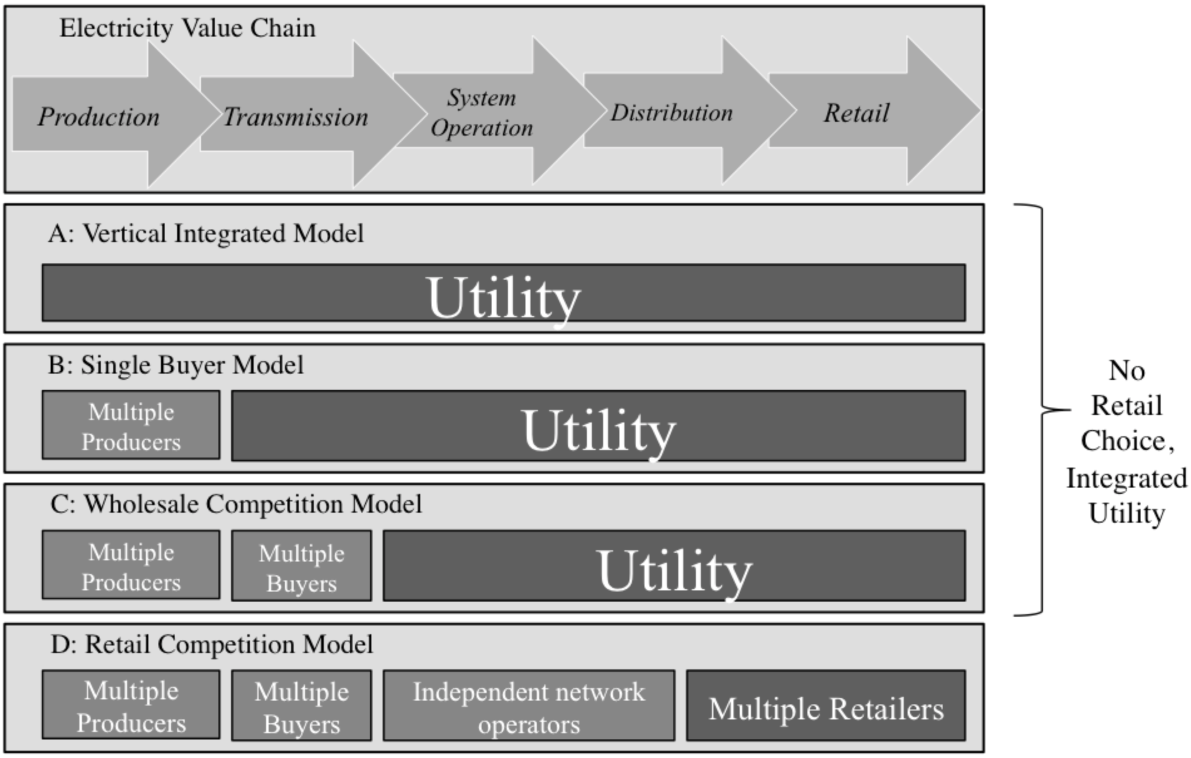
3 Actor perspectives on smart grids

In addition to technical changes, smart grid innovations can require institutional changes in market design, actor roles, and responsibilities. Due to their position, different actors involved in the electricity sector might have very different interests in smart grid developments. Those different actors are, for example, the (public) service utilities, DSO, retailers, aggregators, and electricity customers. Smart grid assets relate to different technical functionalities, which can provide benefits and costs for (some of the) actors involved. A joint report by the Joint Research Centre and Department of Energy (DOE) presented a list of the most common smart grid assets and their functions as used in the USA and Europe (JRC and DOE 2012). Investment in smart grid assets simultaneously influences targets related to affordability, sustainability, and reliability. For example, distribution automation has many benefits for reliability due to the automated/self-healing ability of the network, but can also reduce expenses for network expansion (affordability). At the same time, with large DG penetration, distribution automation can help reach sustainability targets. Alternatively, depending on the way in which the dynamic tariff takes account of policy goals, smart metering and smart appliances can reduce costs for electricity usage, and help support reliability and sustainability objectives. Therefore, depending on the way they are managed, similar assets can be used for different objectives. Due to its multiple functionality, a smart grid can present a different ‘toolset’ for each of the actors involved.

The actors themselves operate within the context of the industry structure. Depending on the structure applied, more or less room is given for competition between actors. Figure 3 presents examples of the most common industry structures. In the US the integrated utility structure prevails (Brooks 2015). In Europe, retail competition is applied due to the European Commission’s (EC) laws regarding functional and legal unbundling of network operators (Newbery 2002; CEER 2013). Unbundling refers to splitting network operation from supply or production activities in order to allow non-discriminatory grid access to all market parties.

Switzerland, however, is not part of the European Union and currently has a wholesale competition model. In China, a single buyer model is applied, where there are two state-owned utilities that deliver electricity in their service area. Due to this diversity, the actors involved are motivated by different interests on smart grid investments. This issue will be further described in Section 4.1.

Figure 3: Possible industry structures due to sector liberalization



Source: Adapted by the authors from Batlle and Ocaña (2013).

3.1 The integrated utility

A strictly vertically integrated utility owns and manages the entire chain of electricity production, transport, and retail. When the production units are not owned by the public utility (which is more common) the utility is either a single buyer of electricity (with one-sided competition), or there is a wholesale competition model in place where different buyers and sellers compete for the lowest price at any moment in time. In this paper we refer to an integrated utility when there is a single retailer present in the area of service, but there is still competition possible in the wholesale market. The integrated utility can be seen in options A–C in Figure 3.

The aptitude of smart grid investments depends on the regulatory approach applied in the sector. For example, under cost of service regulation, capital investments (CAPEX) in smart grids could be more easily approved if the regulator deems such investment as prudent, especially if investments would help to solve imminent grid congestion or supply constraints. Furthermore, the integration of IT and smart grid devices might reduce the need for grid reinforcements or production investments by optimizing the integration of distributed generation. However, many smart grid investments not only involve CAPEX, but also increase operational expenses (OPEX), for example for the procurement of flexibility in real-time operations.

On the other hand, under incentive regulation, as applied elsewhere for integrated distribution companies, incentives might exist to reduce OPEX, for which smart grids might or might not help. Policy makers could support smart grid investments (CAPEX and OPEX) by allowing them to remain outside the regulatory benchmark.

Another issue with smart grid developments and the position of integrated utilities is that due to the monopoly position of the utility, the value, and hence, the price of demand response (of flexible consumption) is not competitively set. Consequently, investments may be hampered by a lack of proper economic incentives discouraging cost-efficient innovation.

3.2 The distribution service operators

In order to give electricity consumers retail choice, it is necessary to unbundle the distribution activity from electricity retail and supply as has taken place in Europe. Generally, the DSO's main task is to keep electricity reliability levels above thresholds by installing enough network capacity and maintaining the grid. Furthermore, the DSO is responsible for providing free third-party access to consumers and producers. Through the established regulatory scheme for the DSO, for example cost of service or incentive regulation, the DSO can recover its incurred costs.

Certain investments in smart grid control devices and metering improve the DSOs ability to get insight into developments and can therefore decrease operational and investment expenses. A DSO can benefit with smart metering from a reduction in metering costs. Furthermore, the procurement of flexibility can delay the need for investments in the network.

In Europe, most DSOs are subject to incentive regulation, which means that their expenses should reduce with an efficiency factor each year. However, the procurement of flexibility through smart grid solutions can increase the operational expenses in time. This can counteract the tendency of the DSO to embark on this route. In several European countries, there is therefore a debate about whether smart grid investments should be left outside the regulatory benchmark.

With respect to unbundling of generation and supply versus transmission and distribution, there is an important difference with respect to the level of unbundling. When the DSO is administratively or legally unbundled (i.e. separated from production and supply while remaining under the same holding company), the holding could maintain (financial) links between the network and generation company. In this case, the smart grid investments by the network company might implicitly benefit other companies in the same holding. On the other hand, with ownership unbundling, the DSO and the generation company are different firms which are strictly separated with respect to the ownership of the assets. In this case, the allocation of smart grid benefits would provide clear benefits that could be transparently allocated to the actors providing the added value.

The Council of European Energy Regulators (CEER) published a report in 2014 that discussed the future role of the DSOs in the European smart grid (CEER 2014). In this report the CEER emphasized that the DSOs should provide a level playing field for other actors in the electricity supply chain. In a response by the association of European Distribution System Operators (EDSO), the DSOs accentuated that all actions that influence grid operations should be carefully assessed (for example installation of new EV charging stations and DG units). Furthermore, they emphasized that if the required regulation for a new activity is of such size that it becomes closely monitored by the regulator, then it should probably be directly done by the DSO itself as an already regulated entity (CEER 2014; EDSO 2015).

3.3 Retailers

Unlike the vertical integrated utility, in a retail competition model retailers are competing for their share of electricity consumers. For retailers, smart metering with insight into real-time consumption could provide more insight into consumption load curves and price elasticity and consequently could result in efficient trading for the supply of electricity. Smart metering and real-time data transfer could enable the possibility of tailored contracts for direct control of devices and real-time pricing, and furthermore could support the provision of incentives for new flexibility services (Hakvoort and Koliou 2014).

Besides supply of traditional electricity retail services, the smart grid could open up new business opportunities for retailers, for example with real-time trading of electric flexibility services on balancing markets, ancillary services, or on congestion markets (Eid et al. 2016). This role could also be fulfilled by the aggregator, which specifically focuses on enabling, management, and trading of aggregated flexibility as presented in the next section.

3.4 New entities: aggregators and energy service companies

Due to integration of real-time data management and control, new business models could arise for new actors in the electricity supply value chain. First of all, the service of electricity supply could be offered by traditional retailers (as presented in Section 3.3). However, this could also be provided by aggregators or energy service companies (ESCOs). ESCOs exist, for example in the United Kingdom (UK) and might combine offers for a range of supplied services like electricity, heating, cooling, and gas supply for a certain urban district (Hannon and Bolton 2015). In addition to the provision of multiple services to the customers, the customer could also trade services to the system with contracts for flexibility through an aggregator (Eid et al. 2016). This aggregator is different to the traditional retailer due to the fact that it specifically focuses on the trading of flexibility services on markets. New actors like aggregators and ESCO might therefore step into the traditional supply chain and provide new services to the consumer, the system operator, and distribution service operator.

3.5 Consumers

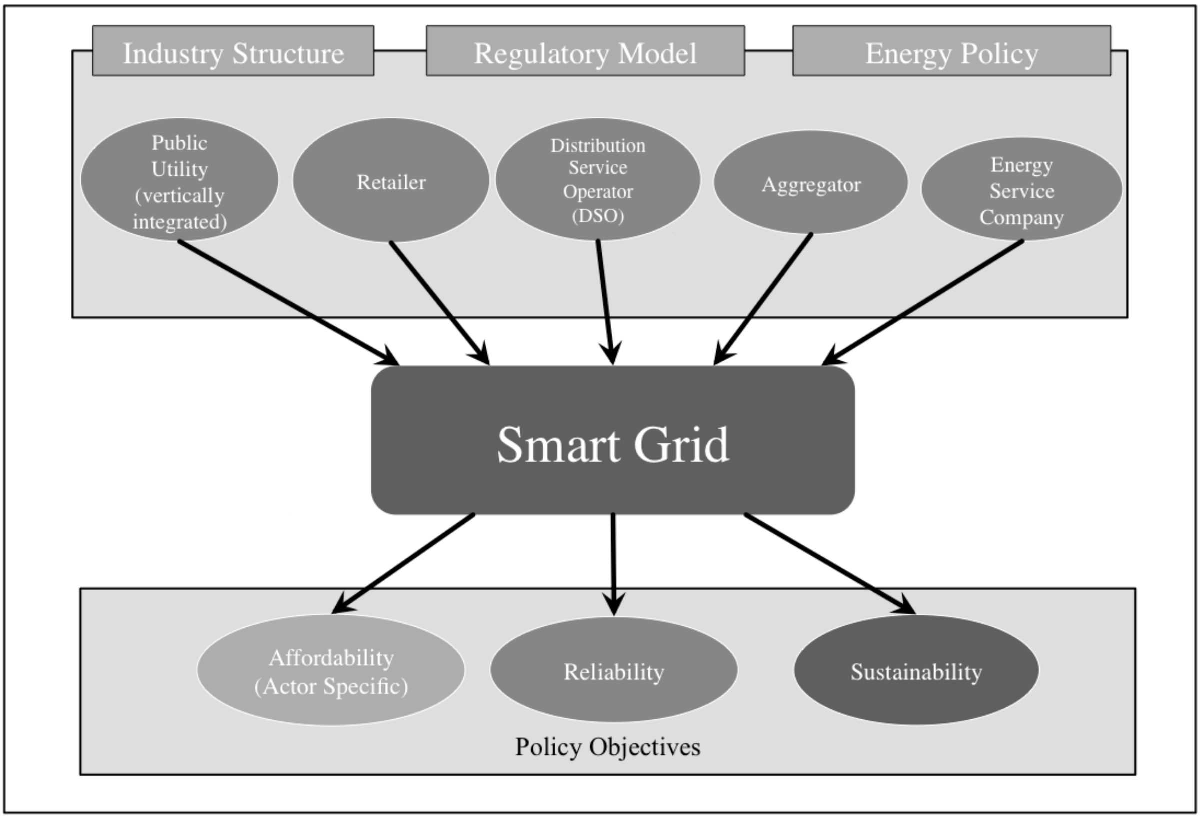
Different to the traditional passive role that residential electricity consumers normally have within the electricity supply chain, the smart grid could open up possibilities for active engagement through real-time insight in consumption data, price changes, local production, and self-consumption of electricity. Both in the design phase of smart grid projects and in the operational phase, this customer engagement is possible. For example, smart grid projects in the Netherlands and Germany show the active engagement of consumers in the design phase of the smart grid with the application of dynamic tariffs and how consumer data is being utilized. From previous experience, it can be seen that privacy should be addressed carefully already in the design stage of the smart grid project to support consumer engagement (McDaniel and Smith 2009; Cuijpers and Koops 2012).

The way in which consumers are engaged is a direct result of the arrangements that have been set out and the services that have been made available for the customer (Hakvoort and Koliou 2014). With the application of dynamic pricing and the installation of in-home displays and energy management systems, consumers can have more control of their consumption and might actively participate in reducing their energy costs and their impact on emissions.

4 Policy perspectives on smart grids

The objectives of electricity security of supply, affordability, and sustainability are important factors for any given energy sector worldwide. Even though these objectives deserve equal importance, they are not 'naturally aligned vectors'. For example, an increase in less-predictable renewables might therefore result in decreased reliability (Macdonald 2013). Often, policy makers promise very positive prospects with smart grids through enabling real-time interactions that enhance sustainability, affordability, and reliability for the electricity sector. Within the subjectivity of the term, is the policy assumption that trade-offs between sustainability, affordability, and security of supply would be reduced with the transition towards a smart grid. The following section presents the main sources for political and economic tensions with the investments for smart grids. Later, from Section 4.2, different developments of smart grids in the US, Europe, and China are presented.

Figure 4: Relationship between market design, actor roles and use of smart grids



Source: Authors' illustration.

4.1 Sources for socio-political tensions

Depending on industry structure, regulatory context, and push from energy policy, a certain (set of) goal(s) could be emphasized with the smart grid (Figure 4). The following subsections highlight those factors, after which developments with the application of smart grids are described in the US, Europe, and China. Table 1 provides an overview of the most important aspects of the diverse policy perspectives on smart grids described in Sections 4.2, 4.3, and 4.4.

The impact of industry structures

As discussed in Section 3, Figure 3, the industry structure provides important insight with regard to type of actors involved in the electricity supply value chain. In the US the integrated utility model prevails, with around 70 per cent of electricity sold coming from integrated utilities. Almost half of these are public utilities (municipality, cooperatives, and others) and the rest are private utilities (Brooks 2015). The customers in those places are not eligible to choose another electricity supplier; they are bound by the local (public) service utility. Frequently those utilities also take care of other services like water and gas supply.

The integrated utility could directly utilize the insight into consumer data for both network and (local) supply optimization. For integrated utilities, however, the possibility exists that due to their monopoly position, the price of demand response (of flexible demand) is not competitively set. Therefore, such investments might lead to too high benefits for the utility. This raises questions about the strategic behaviour of utilities in preventing society from adopting cost-efficient innovation. This is also of importance for China, due to the fact that all electricity for residential consumers results from one of two state-owned companies.

Alternatively in Europe, the retail competition model prevails with the unbundled DSO (except in Switzerland). Depending on the type of unbundling, legal or ownership unbundling has effects on the possible benefits that the DSO could transfer to the retailer associated company. When the DSO is only administratively or legally unbundled (i.e. separated from production and supply while remaining under the same holding company), the holding could maintain (financial) links between the network and generation company. In this case the smart grid investments by the network company might implicitly benefit other companies in the same holding, creating a competitive advantage towards other retailers. On the other hand, under ownership unbundling, the DSO and the generation company are separate firms that are strictly separated with respect to the ownership of the assets. The allocation of smart grid benefits would provide clear benefits which could be transparently allocated to the actors providing added value.

The impact of the regulatory model

As discussed in the previous paragraphs, the industry structure influences which (type of) actors are involved in the electricity supply chain. However, the business model for the network operators and other monopolistic entities depends heavily on the applicable regulation. Due to the fact that the electricity network is monopolistic by nature, electricity transport remains a regulated utility.

There are different ways in which regulators can settle the remuneration for regulated companies. Incentive-based regulations motivate utilities to reduce OPEX and/or capital expenses (CAPEX) in line with an efficiency factor. Alternatively, with rate of return or cost of service regulation, capital investments can be more easily recovered if the regulator deems such investment as prudent. If such smart grid investments require CAPEX expenses (for example, the installation of smart meters), this can be recovered if the regulator agrees. However, many smart grid investments not only involve CAPEX but also OPEX, for example with the procurement of flexibility in real-time operations of the network to delay network expansions. A strict cost of service regulation on CAPEX could hamper a holistic smart grid vision, due to the fact that smart grid assets do not operate 'smartly' without additional long-term operational expenses for procurement, management, and remuneration of electric flexibility that is provided by end-users.

On the other hand, under incentive regulation as applied elsewhere for integrated distribution companies, incentives might exist to reduce OPEX, for which smart grids might or might not help. Policy makers could support smart grid investments by allowing them (CAPEX and OPEX) to remain outside the regulatory benchmark.

Another issue with smart grid performance for integrated utilities is that, due to the monopoly position of the utility, the price of demand response (of flexible demand) is not competitively set. Therefore, such investments might lead to too-high benefits for the utility. This raises questions about the strategic behaviour of utilities to prevent society from adopting cost-efficient innovation.

The impact of energy policy

In order to motivate the sector to contribute to sustainability objectives, policy makers could provide in appropriate financial instruments to motivate investments in smart grids. Policy could be defined strictly top-down, bottom-up, or in a hybrid model (both top-down and bottom-up) and could indicate whether lower policy levels have less or more freedom and power in defining their own strategies.

In some places, certain aspects of the smart grid, for example the smart meter, could be legally enforced by law (top-down), or this could be left to the interests of the utilities involved and the consumers. In some places in Europe (Italy and Sweden), the DSO has been obliged to install smart meters for all consumers. In the European Union (EU) in general a hybrid approach can be observed due to the settlement of (top-down) binding targets (for example the 2020 objectives for sustainability). The principle of subsidiarity, however, implies that member states are free to develop their own energy strategies and implement them in the most appropriate way (bottom-up).

In the US, where federal funding is available for smart metering (the American Recovery and Reinvestment Act of 2009), utilities still have the freedom to decide whether to use this possibility or not, presenting a bottom-up approach for actual implementation. By contrast, in China, a top-down approach is applied, with the state grid company depending entirely on the policy directions given for the roll-out of smart grids.

Table 1: Summary of policy perspectives on smart grids

	United States	Europe	China
Industry structure	Mostly vertically integrated	Retail competition	Vertically Integrated
Regulatory model	Cost of service/rate of return regulation	Incentive regulation for DSO	Rate of Return regulation
Energy policy	Bottom-up	Hybrid	Top-Down
Initial smart grid interests	Reliability & recovery of investments for utilities	Affordability and sustainability	Supply surge of electricity demand in reliable and sustainable manner
Smart grid developments	Smart metering applied in many places, but no greater smart grid vision. End-user left passive in many cases.	Smart metering roll-out only fully done in Sweden and Italy. Remaining problems are the role of the DSO in the retail competition model.	Projects like micro grids and EV pilot projects are deployed on larger scale, where direct control is applied by state grid company. Smart metering and end-user engagement is not main focus.

Source: Authors' illustration.

4.2 The United States' 'smart': reliability of supply

In the US, policy interest in the smart grid arose due to frequent electricity interruptions in 2005, acting as a driver for innovation in the electricity sector (Lin et al. 2013). Later, in December 2007, the concept of the smart grid was established in US legislation, where in the Energy Independence and Security Act of 2007, the smart grid was named as a main pillar for reform (Kaplan et al. 2009). As described in this policy report, this modernized grid would have a large range of features. It would be able to 'self-heal', to motivate the participation of the electricity consumer, to provide power of a quality suitable for twenty-first century needs, to resists attacks, to accommodate all generation and storage options, to enable markets, to optimize assets, and to operate economically efficiently. To implement the proposed smart grid vision, the American Recovery and Reinvestment Act of 2009 (ARRA), commonly referred to as the Stimulus or the Recovery Act, provided US$4.5 billion of funding to modernize the electricity power grid.

Thirty of the largest utilities in the US have fully deployed smart meters to their customers. The states of California and Texas are leading with the penetration of smart meters. Some utilities have included the possibility of alternative pricing programmes, like time-of-use pricing, voluntary peak pricing, and/or even including a larger smart grid vision with in-home energy management systems and displays as in New York and Wisconsin (Edison Foundation 2014). Unlike in Europe, the US electricity sector is mostly structured by the integrated utility model and most residential consumers are contracted with their municipality utility. Apart from in Texas (DEFG 2015), retail choice is not common in the USA. Therefore the penetration of smart metering is carried out in most states through centralized roll-outs, probably due to the high rate of integrated utilities which have a monopoly position to do so. 'However, several states have implemented policies that allow customers to opt-out of smart meters. For those customers typically an initial fee and a monthly opt-out fee are required. The number of customers who have requested to opt-out of their smart meter is relatively low' (Edison Foundation 2014: 1).

Alongside the emphasis on reliability in many smart meter roll-outs, a large range of projects involve experimentation with different smart grid technologies. For example, the University of Delaware's Vehicle to Grid (V2G) project presents an interesting business case for trading flexibility services to PJM, the local Transmission Service Operator (Kempton et al. 2009). Furthermore, the US presents a range of micro grid projects, in which electricity, heat, and gas supply can be locally managed (DOE 2014). Micro grids are grids that incorporate IT to optimize local production with consumption and eventually enable operations in both disconnected and connected mode. The main motives for those projects are reliability and energy independence especially in cases of severe weather events (Bower 2014).

Most utilities, however, continue with smart metering investments, due to the CAPEX nature of those investments and the possibility of receiving a return on investment, but leave out the further smart grid vision with a participative end-user. There is no interest in this due to the reduced income for utilities given the nature of current regulation in many places (cost of service or rate of return regulation).

However, following the provision of funding in 2009, most recent energy policy topics are not related to smart meter deployment, but rather to how to deal with the penetration of distributed energy resources. Due to net metering possibilities and the resulting reduction of energy sales, recovering the costs of fixed assets by utilities is being jeopardized (Eid et al. 2014). Therefore, utilities are currently focusing on the addition of or increase in fixed charges to make up for such costs.

4.3 Europe's 'smart': affordability and sustainability in the liberalized sector

The smart grid concept has been fixed in European policy since publication of the EC's report 'European Smart Girds Technology Platform: Visions and Strategy for Europe's Electricity Networks of the Future' (EC 2006). In contrast to the US, the European system has not faced significant reliability problems. The main drivers for transition to a smart grid were described to be the need for 'fresh thinking' in order to cope with secure and sustainable electricity supplies in the future. Europe's ambitious sustainability objectives do favour a need for new solutions to meet the 2020 objectives of: reducing electricity demand by 20 per cent, increasing renewable share to 20 per cent, and decreasing CO_2 emissions by 20 per cent compared to 1990. The EC set a target for 80 per cent of European households to be equipped with a smart meter by 2020, if the roll-out of smart meters is assessed positively (EU 2009)

Regarding the regulatory context, in Europe the DSO is regulated by incentive-based regulation, meaning that costs for OPEX and/or CAPEX should be reduced in time. Since, in many places in Europe, parts of the network will soon need replacement, DSOs might be interested in the investment opportunities that are available to delay the need for network investments. However, the economic rationale is totally dependent on the regulatory scheme that is in place for recovering costs for both CAPEX and OPEX related expenses for smart grids. Research shows that

> unless the DSO controls electric vehicle charging within an active system management approach, the DSO would have to heavily invest into low- and medium-voltage lines to compensate for local peak demand resulting from EVs. This example from EVs clearly demonstrates the trade-off between CAPEX and OPEX and resulting potentials to avoid unnecessary costs for DSOs (Ruester et al. 2014: 232).

However, OPEX expenses will rise for DSO with smart grid investments and procurement of flexibility for the DSO to replace network expansions. This is not the investment rationale of the DSO and therefore is not supported by European regulation. A different situation for the UK exists due to the fact that the regulatory Office of Gas and Electricity Markets (OFGEM) adjusted regulation for the DSO to take into account other objectives like smart metering (Ruester et al. 2014).

As the DSO is a meant to be a market facilitator in a retail competition model, providing non-discriminatory third-party access to the grid in some places, current legislation limits the DSO to procuring flexibility rather than investing in grid reinforcements. However, dynamic tariffs that vary in both time and place might discriminate customers by increasing price in a geographic area specifically with capacity problems, and not in neighbouring areas without capacity problems (Lunde et al. 2015).

In Europe, so far, only Italy and Sweden have completed a full smart meter roll-out and in both cases the 'degree of smartness' of the metering system has tended mostly to focus on remote meter reading (KEMA 2012a). The motive for installing smart meters in Sweden was the legal requirement to provide monthly invoices based on actual meter readings from 2009 onwards (Bartusch et al. 2011). With remote metering, the 100 per cent roll-out of smart meters would reduce electricity metering costs for the DSOs (Capgemini 2008; KEMA 2012a). However, currently the Swedish DSOs provide time-of-use tariff options in order to shift consumption from peak hours to off-peak hours (Bartusch et al. 2011).

In Italy, the electricity producer Enel initiated smart-meter roll-out in 2000, initially to reduce non-technical losses (KEMA 2012b). More recently, ENEL has also set out a path to move from the roll-out of smart meters to a demand response market platform. Furthermore, the Netherlands has been presenting different interesting cases of smart grid pilot projects since 2012.[2] The projects were subsidized by the Dutch government and in order to expand their experimental scope, they have been allowed to function outside the Dutch regulatory context. Within each project, one DSO is involved together with many other actors such as retailers, IT suppliers, and local energy cooperatives. The different projects provide novel insights into both technical possibilities for local energy management and the required legal adjustments to operate in the Dutch regulatory context of a liberalized electricity market with a fully unbundled DSO. The unbundling of the DSO from the traditional supply chain might lead to different hurdles when alignment is needed with the network capacity limitations and demand response programmes. Therefore, the European DSOs are possibly moving towards new roles in order to attain policy objectives that are of common interest (EvolvDSO 2014).

4.4 China's 'smart': dealing with a surge in electricity demand

Chinese energy policy has focused on growth of the electricity sector in order to keep up with the surge in electricity demand. At the same time, policy efforts have focused on sustainability to reduce emissions and the negative health effects from the high share of fossil-fuel powered production in China (RAP 2013; Brunekreeft et al. 2015). In this context, the Chinese government has acknowledged the importance of smart grids in its twelfth Five-Year Plan for National Economic and Social Development. The report explicitly sets up the goal of accelerating smart grid developments. In line with this policy focus power companies in China, especially the grid operators and academic institutions, are actively promoting their views on smart grids and developing, testing, and deploying smart grid technologies (Brunekreeft et al. 2015).

Chinese transmission and distribution are under the monopoly of one of the two state-owned enterprises. There used to be a regulator in place, but this institution was abolished in 2013. The National Development Reform Commission sets the price by which the monopolies can sell their electricity by means of rate of return regulation.

The ambitious renewable targets in China have stimulated investments in wind and power. The grid is required to be upgraded rapidly in order to handle electricity flows coming from such intermittent production units. China is currently the number one installer of wind power capacity, and number two, after the US, in wind power production. Reduced capacity factors have been attributed to high amounts of forced curtailment, which reached as high as 50 per cent in some regions in 2012 (Davidson 2013). The inflexible planning processes that gave preference to incumbent generators, combined with the volatile nature of production from renewable sources, had disadvantaged wind production (Davidson 2013; Paulson Institute 2015).

Furthermore, most wind, solar, and coal electricity generation is located in the north and far west of China and most electricity consumption is located in the east. Due to this distance between supply and demand, large transmission lines are planned and under construction to connect

[2] See an overview of those pilot projects online at: http://www.netbeheernederland.nl/smartgrids/

generation units with consumption locations. Recently, high levels of investment have been made in the transmission network for ultra-high voltage (UHV) lines. With China being the only country to deploy UHV technology on a large scale, its investment efforts support the international position of Chinese UHV technologies in gaining global market share (Paulson Institute 2015).

In Chinese terms, the smart grid involves a broad portfolio of information and communication technology together with modern technologies for power generation, transmission, distribution, storage, and consumption. This also includes modern grid technologies such as UHV transmission grids or heat-resistant wires. Consequently, smart grids in China focus on all sections of the power system, with a specific focus on the integration of RES (Yu et al. 2012; Brunekreeft et al. 2015). The two state-owned Chinese network companies have invested very highly in transmission network upgrades. Due to their monopolistic nature and their close connection with policy, objectives and directives can be directly implemented in a top-down manner.

In addition to the high voltage transmission perspective of smart systems in China, there are different policy objectives for 'smart grid' at the distribution level. Currently, different pilot projects in distribution networks are operational, with one of the most important projects being EV pilot projects. China's four ministries jointly launched the nationwide pilot programme in 2009 which aimed to roll-out ten new pilot cities each year and deploy one thousand EVs in each city until the end of 2012.

Shenzhen, known as the pilot project city of China, has one of the largest EV fleets in the world. The programme is designed to be city-based. Out of all these cities, Shenzhen had the most ambitious plan, i.e. to deploy 9,000 EVs, followed by Beijing and Shanghai with 5,000 and 4,157 EVs respectively. Shenzhen will be the first city to successfully complete attempts to liberalize sectors (Li et al. 2015). Due to the over-crowded nature of some cities, the government has set maximum quotas on car ownership, but there are no restrictions for EV owners. However, there remains a problem with regard to access to charging stations. Furthermore, the National Energy Administration is planning 30 micro grid demonstrations as outlined in the renewable energy development plan. Apart from the aforementioned projects, residential smart metering and/or dynamic pricing are not part of the smart grid developments in China.

5 Conclusions and policy recommendations

Smart grids have the potential to enable efficient grid interactions, support penetration of distributed generation, reduce emissions, and improve efficiency in the utilization of grid capacity. Furthermore, smart grids can help with the advancement of general energy policy objectives, namely supply reliability, sustainability, and affordability.

The authors of this paper have provided an overview of developments of smart grids within different policy contexts. We defined three main causes of political–economic tensions with smart grid developments in the US, Europe, and China, namely *industry structure*, *regulatory models*, and the *impact of energy policy*.

Firstly, the industry structure defines what actors are involved in the electricity supply chain, ranging from a single (state-owned) utility to a regulated network operator with multiple retailers that compete for their share of customers. Secondly, the regulatory model impacts on how the utility is motivated to invest in smart grid assets, or not, depending on the way its costs are being recovered. Thirdly, the impact of energy policy can differ depending on how energy policy is set in legislation and at what level this is done.

In the US, due to the industry structure and the type of regulation, which is cost of service or rate of return based, the utility invests in smart grid assets if the regulator approves those as prudent. In the past, reliability issues have been the major factor for the development of the initial smart grid. However, after the installation of smart meters, in most places utilities are not directed at further investment in a holistic smart grid vision, simply because the regulation does not incentivize them to do so. With their focus on cost recovery, the current emphasis is on how to handle the reduction in energy sales due to the high penetration of Solar PV, net-metering, and the connection of other distributed energy resources.

The situation is different in Europe where the industry structure is retail competition-based with incentive regulation. Incentive regulation motivates utilities to reduce operational and/or capital expenses over time with an efficiency factor. It is not clear if investments in smart grids are being recovered where they are being restricted by the regulatory framework. In Europe, the policy interest in smart grids began in order to help reach the highly ambitious sustainability objectives. The European Energy directive sets a binding target regarding smart metering if it is assessed that the roll-out would be positive, but member states are still allowed to set up their own roadmaps to reach an overall 80 per cent target of smart metering in 2020 (EU 2009). Consequently, in both Europe and the US a holistic view of smart grids could be hampered due to the fact that generally operational expenses with smart grids and active management of the network will increase, but the regulatory scheme does normally not cover those expenses. Especially in Europe, due to the unbundling position of the DSO, the role of the DSO in smart grids remains unclear.

In China, the surge of the national electricity demand has been the driving force for smart grid policies. The two electricity state-owned enterprises in China have direct links with policy and depending on the stated policy directions by the National Energy Administration, smart grid projects can be approved and implemented in a relatively rapid manner. Most smart grid projects involve electric vehicle pilots and micro grids which are directly managed by the utility. Residential smart metering and/or dynamic pricing are not part of the smart grid developments in China. The quick approach that China has taken in these developments might result in a large-scale smart grids application with, however, limited consumer engagement.

The EU and the US have formulated policies related to the roll-out of smart metering. However, smart grid investment do not (yet) primarily focus on sustainability targets. A holistic smart grid vision would open up possibilities for increased bottom-up participation and better integration of DER at low voltage levels and local energy management. However, due to the traditional regulatory funding schemes for utilities and DSOs involved in those places, the operational expenses for the activation of local flexibility are currently not equally supported. Furthermore, the cooperation models between actors involved in smart grids still remain unclear in many places in Europe, particularly in relation to the role of the DSO.

It is therefore recommended that regulators should allow smart grid investments to remain outside of the regulatory framework. This should not only be the case for smart grid capital expenses, but also for smart grid operational expenses in order to support smart grid developments beyond the installation of smart meters. At the same time, the regulatory institution should be aware of the possibility for excessive benefits that can result from smart grid developments and should specify new indicators for utility regulation in the smart grid context.

A further important dilemma might be related to incumbent power producers and integrated utilities which are dependent on their energy sales from large gas, coal, or nuclear production units. The aspect of stranded costs might reduce the interest for alternative 'smart' investments and developments. Therefore, the role of policy makers should be to reduce regulatory uncertainty and support developments that have a long-term sustainable effect for the energy sector as a whole.

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