Technological Forecasting & Social Change xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

Technology users and standardization: Game changing strategies in the field of smart meter technology

Jochen Markard *, Sabine Erlinghagen

Swiss Federal Institute of Technology Zurich, Department of Management, Technology and Economics, Group for Sustainability and Technology, Weinbergstrasse 56/58, 8092 Zurich, Switzerland

ARTICLE INFO

Article history:
Received 29 June 2016
Received in revised form 14 February 2017
Accepted 16 February 2017
Available online xxxx

Keywords:
Technology standards
Standardization strategies
Technological innovation system
Open standards
Users
Energy

ABSTRACT

Struggles over technology standards are typically reported for competing technology providers. Technology users often play not much of a role in standard development. This paper presents findings from the emerging innovation system of smart meter communication, in which large technology users act as standard developers. This phenomenon is relatively rare, as users often lack the resources and competences to actively engage in standard development. Over a period of 14 years (2000–2013), we track how different standards emerged and changed, why and how users became standard sponsors, and what impact this had on the field. Our analysis is based on variety of data sources, including participatory observation and expert interviews. After an initial period, in which only proprietary standards were available, two large users started to develop open standards together with alliance partners and standard development organizations. Consequently, sponsors of proprietary standards change their strategies, also toward open, alliance-based standards. A central condition for this shift in standardization was that the two users controlled large shares of the market. Our research points to the conditions for user involvement in standardization, thereby contrasting three different settings for standard development. We interpret the case as an example for the larger issue of institutional structures in technological innovation systems developing over time in a patchwork-like way, thereby shaping and changing the conditions for strategic action.

1. Introduction

Technology standards play a key role for the development of technological fields. Standards facilitate the integration of different technological components such as computer platforms, periphery devices and software into coherent systems (Jain, 2012; van de Kaa et al., 2011). Furthermore, standards reduce variety and lower transaction costs (Brunsson et al., 2012; David, 1994), thereby eventually creating economies of scale (West, 2007). Finally, standards also facilitate coordination and cooperation among actors (Brunsson and Jacobsson, 2000; Lawrence, 1999; Timmermans and Epstein, 2010).

For firms and other actors, standards are of major strategic importance as they affect the distribution of resources and the relative positions of players in a field (Brunsson et al., 2012; Lawrence, 1999; Garud et al., 2002). Standard battles, i.e. struggles of organizations over the dominance of standards are therefore a common phenomenon in the development of technological fields (Suarez, 2004). Well-documented examples include VHS winning over Sony's Betamax in the field of video recorders (Cusumano et al., 1992), the struggle of IBM, Apple and Sun for dominance in the field of IT platforms (West, 2003) or the long lasting competition of different standards for mobile telecommunication (Funk and Methe, 2001; Lyytinen and Fomin, 2002).

In most cases, standard battles are fought between competing technology providers that seek to get most out of their proprietary technologies. In contrast to technology providers, *technology users* typically do not play much of a role in standard development (West, 2007; Hawkins, 1995). In fact, there are indications for users being underrepresented in the committees of standard development organizations (Jakobs et al., 2001; de Vries et al., 2003) and the literature reports just a few instances of users actively taking part in the development of technology standards (Lyytinen and Fomin, 2002; Bresnahan and Chopra, 1990; Dankbaar and van Tulder, 1992; Koehorst et al., 1999). A prime reason for this is that most technological fields are characterized by a large number of different users (individuals, private and public organizations) with potentially fragmented interests.

In this paper, we use the technological innovation systems perspective (Bergek et al., 2008; Markard et al., 2015) to portrait a standard battle, in which users - in the form of firms that control major shares of the market - have played a central role. With our study, we shed light on the conditions for and consequences of large users developing standards. A closer look at users is particularly interesting as they can be expected to have diverging interests from technology providers, including a preference for open standards (West, 2007; Bresnahan and Chopra, 1990). Such dynamics are highly relevant both for businesses with strategic

* Corresponding author.
E-mail address: jmarkard@ethz.ch (J. Markard).

http://dx.doi.org/10.1016/j.techfore.2017.02.023
0040-1625/

interests in technology standards as well as for policymakers seeking to spur the development of specific technologies.

In the following, we analyze the development of all major technology standards in the field of smart meter communication in Europe (10 standards of which 3 are user-driven) from 2000 to 2013. Smart metering is an emerging technological innovation system (Planko et al., 2016). Utility companies (more specifically: distribution system operators) are the buyers of smart meters. Together with end consumers, they use smart meter technology, e.g. to track and control power consumption (Erlinghagen et al., 2015). The market for smart meters spans different national electricity markets with different structures. Some markets comprise a large number of small users (distribution system operators), while others are characterized by users that control large market shares. What makes the case of smart meter communication even more interesting is that demand for smart meters in some countries was 'activated' through regulation at different points in time. In other words, the innovation system expanded step-wise and there were different organizations with different standards in different subsystems competing over time.

As of today, the battle over smart meter standards in Europe is still ongoing. What we find though, is a clear trend towards open standards developed by inter-firm alliances. Our analysis shows that the standardization strategies of two large users have significantly contributed to this trend as they delegitimized the originally proprietary strategies of technology providers in the field.

With this study, we do not only enrich the sparse literature on user involvement in standardization but also direct attention to how powerful user interests can change the nature of technology standards and the standardization 'game'. Moreover, we suggest a distinction of ideal-type contexts in which technology standards are developed: These contexts vary in terms of whether they are dominated by technology providers, governments or users and this has implications for how struggles over standards unfold.

The paper is structured as follows. Next, we present the theoretical background and our analytical framework. Section 3 introduces the technological field of smart meters. Section 4 displays the study design. The empirical results are presented in Section 5. In Section 6 we discuss our findings in the light of the literature. Section 7 concludes.

2. Theoretical background

Standards are agreed-upon rules "about what those who adopt them should do" (Brunsson and Jacobsson, 2000, p. 4); they both enable and constrain action thus facilitating coordination among actors (Timmermans and Epstein, 2010). Here we concentrate on *technology standards*, which are formal standards that specify the properties, a product or technology must have, to be compatible with other components and to be integrated smoothly into a larger technical system (Jain, 2012; Brunsson et al., 2012). Technology standards can be viewed as formal institutions in a technological innovation system (Bergek et al., 2008; Musiolik and Markard, 2011). Technology standards are created, reproduced and transformed by the actors in the focal field (Brunsson et al., 2012; Garud et al., 2002; Slager et al., 2012).

2.1. Users in standard development

Technology standards have received quite some attention in economics, management and innovation studies due to the profound impact they have on technology development (exponential growth, dominant designs, lock-in) and the fate of firms (Suarez, 2004; West, 2003; Narayanan and Chen, 2012; van den Ende et al., 2012). The overwhelming majority of studies have looked into technology providers and/or governments involved in standardization, which is why we know comparatively little about how *technology users* affect standard development.

This gap is essential because technology providers and users may have very different interests. It can be assumed that technology providers want to recover their development costs and generate high revenues from a novel technology, while users want the products or services that spawn from the technology to be low cost. Users also prefer a high degree of compatibility to benefit from a broad range of complementary products and not become locked in (Bresnahan and Chopra, 1990; Dankbaar and van Tulder, 1992). As a consequence, users tend to prefer open standards that are widely accessible for a broad variety of competing technology providers and complementors (West, 2007).

To date, the literature on standardization reports just a few examples of users assuming the role of standard developers, or sponsors (Lyytinen and Fomin, 2002; Bresnahan and Chopra, 1990; Dankbaar and van Tulder, 1992; Koehorst et al., 1999). A prominent case in this regard is MAP, an IT communication standard for factory automation, that was developed and promoted by General Motors in the 1980s to better integrate pieces of equipment from different technology vendors (Bresnahan and Chopra, 1990; Dankbaar and van Tulder, 1992). GM's initiative as a large technology user was later supported by other automobile manufacturers, by large firms in the aircraft industry and by the US military. Another example is the development of 1st and 2nd generation mobile phone standards, in which national telecommunication network operators (in their role as technology users), technology providers and governments played an influential role (Funk and Methe, 2001; Lyytinen and Fomin, 2002).

While from these studies we have learned much about the interests of users, we still know little about how users and providers interact as they compete as standard sponsors in an emerging technological field.

2.2. Analytical framework: novel technologies in existing contexts

In the literature on innovation studies, the technological innovation systems (TIS) framework is a widely applied perspective scholars use to analyze emerging technologies (Bergek et al., 2008; Markard et al., 2015). Among others, the TIS framework directs attention to the key role of actors and institutional structures, both affecting technology development.

New technologies do not emerge in an 'empty space' but in the context of existing markets, industries, professions, regulations, societal values, culture etc. (Garud et al., 2002; Muzio et al., 2013; Wirth et al., 2013). We can think of the context as a patchwork of semi-coherent institutional and organizational structures that affect the way, in which firms and other players interact when developing the focal technology (Bergek et al., 2015). In other words, there is not just one context but a variety of different context structures for an emerging technology to cope with.

We expect a focal TIS to reflect these context differences and to show patchwork-like structures (e.g. in the sense of sub-systems), especially in early stages of development. At the same time, as the innovation system matures, it will develop common overarching institutional structures such as technology standards, dominant designs, collective expectations or shared practices of use. In our study, we will come across different TIS sub-systems, in which the influence of users on standard development varies.

Several studies have shown that novel technologies do not necessarily develop evenly along a global trajectory, but that socio-technical configurations may vary depending on the context conditions in different regions, countries or sectors (Wirth et al., 2013; Dewald and Truffer, 2012; Hansen and Coenen, 2015). Technology development can be viewed as the interplay of local activities in specific areas, or sub-systems (e.g. national markets), and more general, overarching processes at level of the entire technological innovation system. Also standards may unfold both locally and globally. In mobile telecommunication, for example, standards were first (in the 1980s) developed at national levels and later (1990s onwards) also internationally (Funk and Methe, 2001).

Another important aspect in the emergence of technological innovation systems is the role of different kinds of actors and their strategies toward 'system building', i.e. the deliberate creation or modification of institutional and organizational structures (Planko et al., 2016; Musiolik et al., 2012). System building comprises a broad variety of activities, including the creation of value chains, the development of educational programs or creating technology legitimacy (Kukk et al., 2015; Markard et al., 2016; Wesseling et al., 2014). Standard development is a typical example of system building.

2.2.1. Main actor groups

There are five main groups[1] of actors in standardization, based on the general roles actors can assume in the value chain (West, 2007). *Technology providers*[2] are firms that develop and supply the technology or product (e.g. DVD drive) for which a standard will be specified. *Users* buy and use this product (e.g. to record and watch movies). Below, we focus on commercial users (here: distribution system operators, DSOs) that use the product to optimize their processes and to offer services to their customers. *Complementors*, are firms that provide products or services that complement the core product (Markard and Hoffmann, 2016). They also use the standard to ensure compatibility with the core technology. *Standard development organizations* (SDOs) are quasi-official intermediaries, which facilitate the process of standard development. SDOs rely on expert committees with experts typically employed by technology providers or consulting firms in the field. SDOs work with formalized processes, in which standards are eventually selected by the vote of committee members (Brunsson et al., 2012). *Governments*, finally, may mandate a standard or set incentives for stakeholders to arrive at a common standard.

All of these actors may assume the role of *standard sponsor*. Standard sponsors are those organizations that take the lead in the development and promotion of a standard. Often, these are technology providers such as JVC and Philips in the case of VCR standards (Cusumano et al., 1992), or SDOs such as the Institute of Electrical and Electronics Engineers in the case of the Ethernet standard (Jain, 2012). Also governments have been reported to initiate and shape standardization, e.g. in the field of mobile telecommunication (Funk and Methe, 2001; Lyytinen and Fomin, 2002).

2.2.2. Standardization strategies

Standard sponsors can pursue different strategies in how they develop a standard. A major distinction can be made between the process of standard development (e.g. individual vs. collaborative) and the nature of the standard (e.g. proprietary vs. open).

2.2.2.1. Mode of development. If an actor develops and pushes a technology standard on his own, we refer to this as the *single firm mode*. Examples include the case of Sony with Betamax and PlayStation (Suarez, 2004), Sun with Java (Garud et al., 2002) or Apple with its IT platform (West, 2003).

Very often, however, standard sponsors team up with other organizations, even including competitors from the same industry. We will refer to such a cooperative way of standard development as the *alliance mode*. Building stable and influential alliances can be quite decisive in standardization battles (van den Ende et al., 2012; Leiponen, 2008). Despite being first in the market, Sony lost against JVC in the VCR standard battle primarily because JVC was more active and successful in creating alliances (Cusumano et al., 1992).

A third mode, the *SDO mode*, is about a standard development organization governing standard development (Brunsson et al., 2012; de Vries et al., 2003). The case of mobile communication technology is an example for standardization processes governed by SDOs (Funk and Methe, 2001). The SDO mode is similar to the alliance mode in terms of multiple organizations, and interests, participating in standard development.

From a strategy perspective, the three modes can be viewed as positions in a continuum, in which a private standard sponsor has more (single) or less (SDO) influence on standard development, while receiving more (SDO) or less (single) support by other actors.

2.2.2.2. Openness of a standard. Standards can be proprietary or open. In the case of proprietary standards, the standard sponsor determines the content of the standard and can also restrict its use (e.g. through property rights). For open standards such restrictions do not apply. Again there is a continuum and standards are rarely entirely open or entirely proprietary (West, 2007).

Openness can include two dimensions: If standard use is open, it can be implemented by all interested parties at low (or no) costs. If standard development is open, demands of different stakeholders can be incorporated. This might even imply an ongoing adaptation of the standard as the base of stakeholders expands and/or demands change. For the success of Blu-ray, USB and WiFi standard adaptation and subsequent expansion of the circle of supporters was essential (van den Ende et al., 2012).

From a strategy perspective, the openness of a standard directly affects the possibility of standard sponsors to generate returns. Increasing openness makes generation of returns more difficult (Garud et al., 2002).

3. Smart metering in Europe

Smart metering is a novel technology primarily used in the electricity sector. Smart meters are installed in residential and commercial buildings for a variety of functions including remote metering, network monitoring, load management, flexible pricing, energy saving or integration of distributed electricity production (Depuru et al., 2011; Farhangi, 2010). Smart meter communication standards are essential as they define the rules for information exchange between meters, data concentrators and back-end systems and the underlying communication technology (Erlinghagen et al., 2015).

As of 2013, more than 60 million smart meters were installed in Europe, which means that about every 4th household is equipped with a smart meter (European Commission, 2014).[3] Diffusion of smart meter technology varies significantly across countries. Italy, Sweden, and Finland already exhibit diffusion rates close to a 100% and in Denmark, Spain, France and the UK smart meter installations are well under way with rates between 10 and 50% (Colak et al., 2015; Covrig et al., 2014). The diffusion of smart meter technology is – to quite some extent – driven by regulation. The EU targets an 80% penetration of smart meters in European households by 2020 (European Commission, 2009).

Since 2000, different smart meter standards have been developed and diffused in Europe. Fig. 1 shows their cumulative diffusion until 2013 and a projection[4] until 2020. Telegestore (today Meters&More) was the first. In 2013, it was the standard with the largest installed base (cf. Fig. 1). Five further smart meter standards (LON, PLAN, GSM, Kamstrup RF and Meshnet) were developed and applied in the early years of smart metering. So far, they have not diffused widely. More

[1] With this categorization we do not mean to exclude other types of actors such as scientists or social movement organizations that may also play a role in standard development.

[2] Note that there is typically a network of different firms involved in the development and provision of a specific product or service. With technology provider we apply a simplified view on this and refer to the firm that plays a central or dominant role in this network. We also use the term technology developer or vendor as alternatives.

[3] These figures are comparable to the US electricity market with 43 M smart meters installed in 2012 and a penetration rate of about 25% (http://www.eia.gov/tools/faqs/faq.cfm?id=108&t=3, accessed June 30, 2014).

[4] Such a projection is possible for those cases where utilities have already announced which technology and standard they will use and when their roll-out will be completed.

Please cite this article as: Markard, J., Erlinghagen, S., Technology users and standardization: Game changing strategies in the field of smart meter technology, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.023

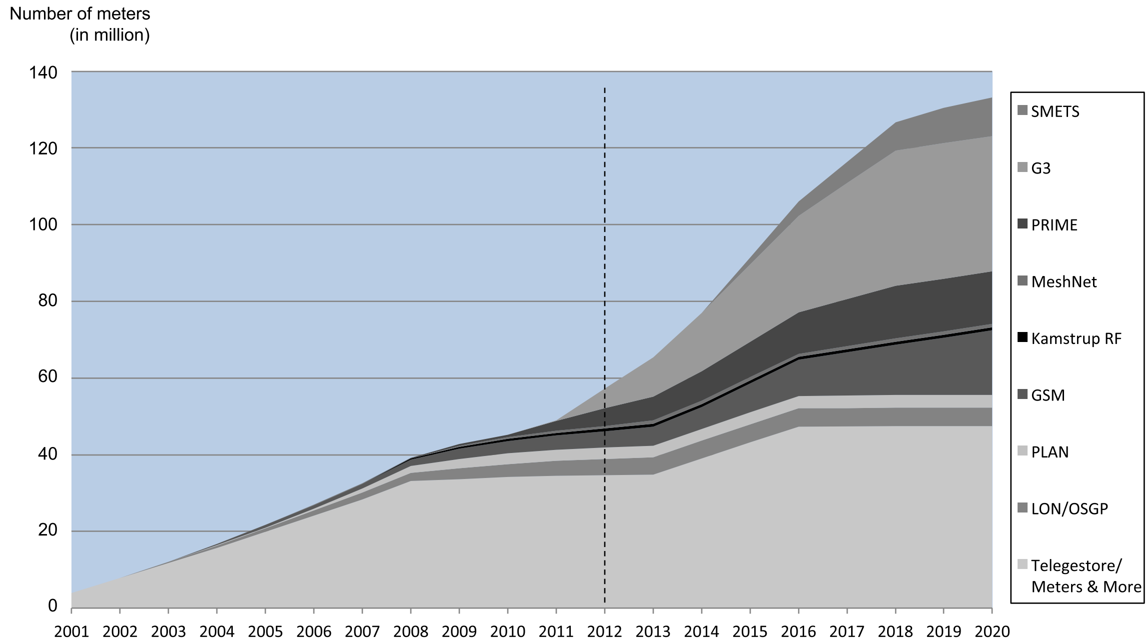

Fig. 1. Cumulative diffusion of standards in Europe until 2012 and projection until 2020. Standards appear in the order of development (newest on top). Does not include projections on German FNN standard, as they are not yet available. Counts meters as "SMETS" if deployed in UK regardless whether they are based on GSM and MeshNet.

recently, another four standards (Prime, G3, SMETS and FNN) have been developed and will be deployed in significant numbers.

The technological field of smart metering in Europe comprises hundreds of actors (Covrig et al., 2014). Key actors include traditional meter suppliers such as Landis + Gyr, Kamstrup or Siemens, chip manufacturers like Texas Instruments or STMicroelectronics, and telecommunication service providers such as Vodafone or Telefonica. Distribution system operators such as Enel, ERDF, E.On, Iberdrola or Vattenfall are the primary users of smart meter technology. They buy smart meters from technology providers to install and operate them at the premises of their customers. Governments play a role as some have mandated distribution system operators to roll-out smart meters. These mandates typically leave open which communication standard to use. In the UK and Germany though, governments have prescribed mandatory standards. Active standard development organizations include CENELEC on the European level and IEEE or IEC on the international level. These are specialized in electrical technology. Also ETSI and ITU, two SDOs for telecommunication, are involved in smart meter standardization.

A particularity is that smart metering comprises a variety of national markets that differ in terms of size and structure, the role of governments and when smart meter activities started (Colak et al., 2015). Italy, France and Spain are countries with very large, dominant distribution system operators (technology users), whereas markets in Sweden, Finland and Germany are characterized by many small users (Table 1).

4. Methodology

In our research, we applied a case study set-up including a longitudinal analysis. Below we explain how we obtained and analyzed our data.

4.1. Research site and scope of analysis

Given our interest in the role of users, the smart meter technology is a suitable case for two reasons. First, it is an innovation system, in which large users with significant market power are present. In fact the field is characterized by national electricity markets with very different structures when it comes to smart meter users (cf. Table 1). Furthermore, there are some countries with government intervention in standardization and many without. This variety allows us to compare the strategies of standard sponsors across different contexts, or settings.

Secondly, the field is characterized by an almost sequential, country-by-country diffusion pattern. This pattern occurred, among others, because of government mandates for nation-wide smart meter roll-outs that were issued at different points in time. This allows us to compare changes in standardization strategies over time and to link these changes to the 'activation' of different types of settings.

Our study covers all *major* smart meter standards in Europe. 'Major' means that we have included actual and planned installations larger than 50,000 meter endpoints. In a longitudinal design, we analyze standard development from its beginning in 2000 until 2013.

4.2. Data collection and analysis

This study builds on unique access to primary data sources including 'in situ' observations, archival material and experts (informal discussions and formal interviews). This data was complemented by a comprehensive analysis of publicly available documents.

4.2.1. Data collection

Data gathering comprised three main parts: 'In situ' observations, document analyses and expert interviews. Personal observation was possible thanks to the access to a leading technology developer in the field. Between 2011 and 2013, one of the authors regularly attended strategy meetings of this firm. The author also attended the major industry conference on smart metering in three consecutive years (2011–2013). Both venues offered the opportunity for many informal discussions. These were particularly helpful to check and challenge the information from the interviews and secondary data.

The second part of our data collection consisted of a comprehensive analysis of documents that helped us to understand the current situation and to trace earlier developments. We started with a systematic review of the websites of all ten standard sponsors, including standardization alliances. Next we reviewed news articles from specialized industry journals, industry reports, conference presentations and a

Please cite this article as: Markard, J., Erlinghagen, S., Technology users and standardization: Game changing strategies in the field of smart meter technology, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.023

Table 1
Key characteristics of selected national markets for smart meters in Europe.

Start of smart meter standard activity	Countries	No. of users	No. of meters of largest user	Total number of meters	Characteristics of country
2000	Italy	6	32 M	36 M	Early adoption, large country, large user
2003	Sweden	158	1 M	5.3 M	Early adoption, many, small users
2003	Finland	80	0.6 M	3.3 M	Early adoption, many, small users
2007	Spain	3	13 M	28 M	Large country, large user
2007	France	1	33 M	33 M	Large country, large user
2011	Germany	800	7.6 M	44 M	Large country, government decision
2011	UK	6	7.5 M	28 M	Large country, government decision

case study on the Italian smart meter roll-out in 2000 (cf. Rossi et al., 2009). These archival documents allowed us to trace back changes in standardization strategies between 2000 and 2013. Particularly helpful were conference presentations held by standard sponsors at the leading European industry conference, which were available from 2005 to 2013.

The third part comprised a total of 26 expert interviews. A first series of 8 interviews had an explorative character. As interview partners we selected experts that have been involved in the development of smart meter standards for many years, ideally from the beginning (i.e. CTOs, members of alliance boards and standardization committees). Several interviewees had even worked on different standards, so they could compare developments.

Building on this, we conducted another 18 interviews with standard sponsors, including all three large users (ERDF, Iberdrola and Enel), technology providers sponsoring competing standards and technology providers participating in SDOs or standardization alliances. We selected managers responsible for (or involved in) strategic decisions around standard development and deployment. We interviewed at least two experts for each standard under analysis, with some interviewees reflecting on more than one standard.

All 26 interviews were conducted between October 2012 and October 2013. They lasted between 60 and 90 min. If possible they were conducted in person (16 of 26), otherwise by phone. If informants agreed, the interviews were recorded (10 of 26). In all cases, extensive interview notes were taken during the interview and a protocol completed immediately after.

4.3. Categorization of standardization strategies

We classified standards as ‘single firm mode’, when a standard sponsor developed the standard individually. This includes cases in which the firm commissioned the development of parts of the specification to third parties. If, in contrast, a standard sponsor created a formal alliance (e.g. indicated by statutes), which owns the standard and governs its development, we refer to this as ‘alliance mode’. The ‘SDO mode’, finally, refers to cases in which either an SDO is the standard sponsor or a standard developed by a firm or alliance was endorsed by an SDO.

Furthermore, standards were classified as proprietary if only the standard sponsor decides about the standard content and if implementation is not possible for third parties. In contrast, if - at least - alliance partners (or committee members) are allowed to participate in the development of the specifications and if both, partners and third parties, can implement the standard (at no or non-prohibitive license fees) we regard a standard as open. If participation in the development was not possible but specifications were available for broader implementation we refer to it as semi-open.

5. Results

This section consists of three parts. First we briefly describe the development of the different standards and how standardization strategies changed over time. Then we report on how and why users developed their own standards. The final section covers which impact the user strategies had on the field and the strategies of others.

5.1. Development of standards and changes in strategies

Table 2 lists the 10 standards we analyzed, their sponsors and the strategies the sponsors pursued, both initially and in 2013. Two standards were already developed in the 1990s but for different purposes. Major changes occurred from 2007 onwards, including alliance building, SDO involvement and standards opening up (cf. Fig. 2).

5.1.1. Initial developments

Standard development started in 2000 with the decision of Italy's dominant electric utility/DSO Enel to roll-out smart meters to its entire electricity consumer base with more than 30 million meters. For that purpose a communication standard was needed but there were no products and standards readily available in the market. PLAN was a technical specification, which was neither tested nor implemented in any product and GSM/mobile phone technology was too expensive back then. Enel therefore decided to develop a new wire-based communication standard (Telegestore). It sought support from several partners, including chip and meter manufacturers or IBM as system integrator (Rossi et al., 2009). Initially, Enel also partnered with Echelon (see below) but discontinued this relationship in 2003. Enel kept the technology proprietary and acted as a single sponsor. In 2004, Enel

Table 2
Major smart meter standards in Europe - changes in the underlying standardization strategies.

				Initial strategy		Strategy in 2013	
Year when standard development started	**Standard**	**Sponsor**	**Actor group**	**Development mode**	**Openness**	**Development mode**	**Openness**
1990s	**GSM**	**Telco firms**	Tech provider	SDO	open	SDO	open
1990s	**PLAN**	**Meter firms**	Tech provider	SDO	open	SDO	open
2000	**Telegestore**	**Enel**	Tech provider/user	Single firm	proprietary	Alliance	open
2001	**LON**	**Echelon**	Tech provider	Single firm	proprietary	Alliance/SDO	semi-open
2003	**KamstrupRF**	**Kamstrup**	Tech provider	Single firm	proprietary	Single firm	proprietary
2004	**Meshnet**	**Connode**	Tech provider	Single firm	proprietary	Alliance/SDO	semi-open
2007	**PRIME**	**Iberdrola**	User	Alliance	open	Alliance/SDO	open
2007	**G3**	**ERDF**	User	Alliance	open	Alliance/SDO	open
2011	**FNN**	**German Gov**	Government	SDO	open	SDO	open
2011	**SMETS**	**British Gov**	Government	SDO	open	SDO	open

Please cite this article as: Markard, J., Erlinghagen, S., Technology users and standardization: Game changing strategies in the field of smart meter technology, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.023

decided to sell its Telegestore technology to other utilities as well. From then on, Enel also became technology provider, next to being a user

Echelon, a communication technology provider from the US with experiences in building automation, developed its LON technology into another proprietary standard suitable for smart metering. In 2003, it acquired know-how from a small metering firm so that it could not just offer communication technology but also a complete smart meter. From then on, Echelon pursued a dual strategy of selling entire smart meters as well as LON chips and licenses to other meter manufacturers. Echelon and other meter vendors successfully sold LON-based meters to many Swedish, Finnish and Danish utilities between 2003 and 2007.

Kamstrup, a Danish firm with a long tradition in heat metering, developed a proprietary wireless standard in 2003 to address the emerging Danish market for smart meters. Kamstrup sold meters with its own communication standard, but also offered meters that use mobile phone/GSM technology. Unlike Echelon and Connode (see below), Kamstrup did not license the standard to other meter manufacturers. The KamstrupRF standard was successfully sold to Swedish utilities.

Connode was founded in Sweden in 2002 with the goal to respond to the demand for smart metering in the Nordic countries. Its Meshnet standard was initially a proprietary wireless standard, thus directly competing with Kamstrup. Unlike Kamstrup, however, Connode did not offer meters but focused on selling Meshnet to other meter manufacturers or directly to utilities, if the communication technology was tendered separately. Connode was successful in Sweden and even more so in Finland.

Iberdrola, a large electric utility/DSO in Spain, developed its own standard called PRIME in 2007. By that time, Iberdrola was under pressure because of a mandate from the Spanish government to roll-out smart meters until 2018 and because of another large Spanish utility (Endesa) moving ahead with its roll-out.[5] Iberdrola developed PRIME as an open standard. From the beginning, Iberdrola cooperated closely with a Spanish chip manufacturer, a Spanish meter manufacturer and other partners. In 2009, it formed a broader alliance with technology providers and complementors with three goals: to further develop the standard, to perform conformance testing and certification of products and to market the standard to other users.

ERDF, the dominant DSO in France, decided to roll-out smart meters in 2007, after a mandate of the French government. ERDF asked Maxime, a large US electronics company, to develop the initial specification of the so-called G3 standard. ERDF then published the specification to promote an open standard. In 2010, it invited other technology providers and complementors to form an alliance with much the same goals than previously Iberdrola.

The two government-driven standards in the UK and Germany, finally, were developed as open standards by governments and national standard development organizations. Governments assumed a coordination role inviting technology providers and users to jointly develop a standard. The standards were then handed over to national SDOs. So far, these standards are foreseen for deployment in the respective country but not actively promoted for use in other countries.

In summary, the initial standardization strategies differed substantially. Technology providers pursued proprietary strategies, while users and governments sponsored open standards. Technology providers (including Enel) started with a single firm mode, while Iberdrola and ERDF sought support in broader alliances. All three user-DSOs (Enel, Iberdrola and ERDF) collaborated with technology developers from the beginning.

5.1.2. Changes in standardization strategies

The initial strategies saw major changes (Table 2). Enel was the first to change its standardization strategy in 2010 as it transformed its proprietary Telegestore standard into an open standard, also using a new name: Meters&More. Moreover, Enel founded the Meters&More alliance with other users (Endesa and E.ON), chip manufacturers, meter vendors and complementors. Alliance partners are also involved in developing the standard further.

Echelon opened its standard in 2010 by releasing the specification of its LON standard to its user group. Similar to Enel, Echelon re-named the standard into Open Smart Grid Protocol (OSGP). The user group, now called OSGP alliance, facilitates exchange of knowledge and experience among users of the standard but it does not directly contribute to further development of the standard, which is why we consider the current status as semi-open.

Connode started to develop an open version of its Meshnet standard in 2012. However, instead of releasing the specification of their Meshnet standard, Connode defined the next version of MeshNet entirely based on specifications of several existing, open communication standards. The new version is based on a tool kit of global open (sub)standards such as 6LoWPAN/IPv6 and CoAP. Connode also joined the standardization alliances that promote these standards.

Kamstrup, in contrast, did not open its standard. But the firm emphasizes its flexibility to sell meters that employ other open standards such as GSM or M-Bus. Moreover, Kamstrup launched Omnia as a platform concept in 2012. This platform can accommodate several different communication standards – including Kamstrup RF. Kamstrup seeks to win complementary partners for their platform.

Changes in standardization strategies also included endorsement by third parties: In 2011, PRIME, G3, Meters&More, PLAN and GSM/GPRS were certified to be compliant with the requirements of the OPENmeter project and the related mandate of the European Commission. In the same year, PRIME, G3 and OSGP sought acceptance by standard development organizations. To summarize, strategy changes were essential and widespread. As the two large users, Iberdrola and ERDF, seem to have played a key role in this, we now look into their motivations and how the other sponsors justified their strategy changes.

5.2. Motivations of users promoting open standards

The strategic decisions of Iberdrola and ERDF in 2007 were two-fold. First, they decided to become standard sponsors themselves and second, they pursued and open, alliance based strategy. The motivations of both players are very much in line. In the interviews, they highlighted three crucial points: They wanted an interoperable standard that could be implemented at low costs, they wanted to avoid lock-in with a single meter vendor and they were looking for a standard that fulfilled their technical requirements.

> "We wanted a cheap solution and an open solution where we can choose from multiple vendors … a proprietary solution does not help to bring the prices down. People were talking about 100 EUR per meter at that time [which was too expensive]."
>
> [(Iberdrola)]

> "…[we want] to choose from many suppliers and prevent lock-in with a single vendor. Secondly, we want a robust standard and we want a modern standard."
>
> [(ERDF)]

> "In a first step we looked at what other utilities had done. But everything we found was proprietary. Swedish utilities had 3 different standards in their distribution grid. Enel had a proprietary standard [as well] ..."
>
> [(ERDF)]

With regard to their standardization strategies, Iberdrola and ERDF pointed out three main reasons why they chose an open, alliance based strategy. Firstly, an open standard was expected to initiate

[5] Endesa is owned by the Italian Enel and therefore used the Telegestore/Meters&More standard.

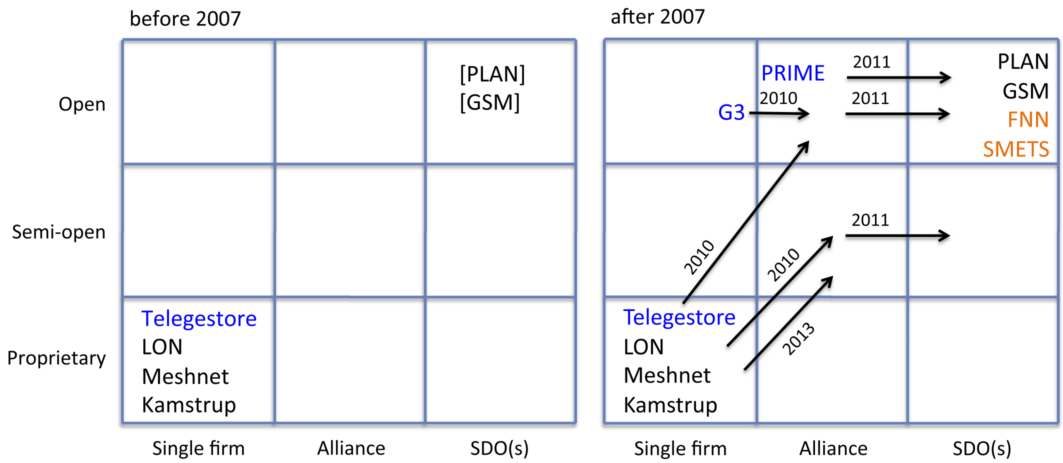

Fig. 2. Changes in standardization strategies over time (blue: user driven standards; orange: government driven standards).

competition among technology providers, thus promising lower prices and preventing vendor lock-in.

> "Openness is the main characteristic for allowing real competition avoiding any proprietary design ... Utilities are at the forefront of the roll-out of millions of meters, any single Euro that utilities can save in meters has to be multiplied by millions… [we wanted] a solution that can be performed by any chip manufacturer and any meter manufacturer, with real competition – that is really the saving"
> [(Iberdrola)]

> "…an open standard allows us to choose from many suppliers and prevents lock-in with a single vendor ... In the end, [technology providers] are all alligators. All collaborate in the alliance, but they are competitors."
> [(ERDF)]

Secondly, an alliance was seen as a way to overcome their lack of technological competencies and to ensure that equipment vendors implement the standard in their products. Finally, they saw advantages for the quality of the standard as they mobilized input of many parties.

> "As a utility we knew what we wanted ... but we did not have the ability to do that. We engaged with silicon manufacturers. For the prices to go down ... we needed mass production of chips. ... We engaged with academic experts to know about OFDM tech ... [and] with companies with extensive communication technology know-how in the media access layer. And finally with meter manufacturers who need to integrate this technology in their meters."
> [(Iberdrola)]

> „For us, the rationale for an open standard [developed in an alliance] was mainly to benefit from the developments of others. The open standard allows us to get many contributions from many parties. You get more back than you gave away."
> [(ERDF)]

Neither ERDF nor Iberdrola had initially planned to develop a new standard. They only decided to do so, when they found that none of the existing standards matched their interests. The existing standards were either proprietary or otherwise not suitable: PLAN and GSM being the only open standards in 2007 were found to have technical limitations and too expensive (GSM). In addition, GSM implied the outsourcing of the operation of the communication network, which creates dependence on a third party.

Respondents from Iberdrola and ERDF also highlighted, why the promotion of the standard outside of Spain and France was an important cornerstone of their strategy. Suppliers were expected to benefit from a larger market for their PRIME and G3-based products, while the users themselves benefit from lower prices thanks to economies of scale and competition between vendors. In the interviews, this was depicted as a win-win situation.

> "G3 should become the world-wide PLC standard. For that you need around 100 million meters installed. 35 million meters [of ERDF in France] are just not enough volume for a global standard. Chip manufacturers want larger volumes."
> [(ERDF)]

5.3. Impact of user-sponsored standards

A common impression of our interviewees is that the two users set in motion a general trend towards open standards, developed in alliances and endorsed by SDOs.

> "ERDF and Iberdrola started this trend towards open standards. They did not accept proprietary standards, they wanted an open standard that ensured interoperability between products of different technology providers."
> [(meter manufacturer)]

> "[competing against G3 and PRIME] you cannot have proprietary standards. This is not accepted by users."
> [(technology provider)]

At the same time, also Enel saw itself as an initiator of the new trend:

> "When we started with the open standard, this triggered a big change in the market. From one year to another at Metering Europe in Amsterdam [the European fair on smart grids] everybody was talking about open standards."
> [(Enel)]

The size of the market controlled by Iberdrola and ERDF was certainly decisive for the impact the two had on the field. It convinced technology providers and complementors to join the alliance and to also use the standard:

> "If we want to win a metering deal in France or Spain, we have to support these standards. These markets are too big for us to ignore."
> [(meter manufacturer)]

As a consequence, alliances around these standards grew substantially and helped creating momentum behind these standards. In addition to that, other utilities learned from Iberdrola and ERDF and also

Please cite this article as: Markard, J., Erlinghagen, S., Technology users and standardization: Game changing strategies in the field of smart meter technology, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.023

asked for open standards as a mandatory requirement in their tenders. This put even more pressure on technology providers with proprietary standards. If they did not want to be excluded from large parts of the markets, they had to open their standards.

> "… today you cannot have proprietary standards. This is not accepted by users. … Openness is a requirement in many tenders today."
> [(Echelon)]

> "… [today] nobody wants to say that I have a proprietary system. Because I imagine that at the utility level that does not sound very good. They want to have something that is [open] standards based technology..."
> [(chip manufacturer)]

> "I don't know of a utility that would accept a proprietary standard, today"
> [(meter manufacturer)]

More importantly, other users could even choose G3 or PRIME themselves due to the fact that Iberdrola and ERDF promoted them internationally. As a consequence, several European and international utilities decided for these user-driven standards. EDP in Portugal and Energa in Poland decided for PRIME, while Tepco in Japan has decided for G3.

> "Tepco in Japan [wanted an open standard], they decided for G3 and other utilities are about to decide [for it]. Enexis for example is promoting G3 to other utilities…."
> [(ERDF)]

Technology providers, sponsoring proprietary standards, had to react. An interview partner from Enel, for example, pointed out that they opened their standard and founded the Meters&More alliance primarily as a reaction to the competition with PRIME in the context of the European Commission's M/441 mandate to recommend a European standard. He explained that despite its large installed base, strategy makers at Enel thought they could only win against PRIME if they would open up their standard as well.

Fig. 2 positions the standards according to our two key dimensions and how they developed over time. Before 2007 the innovation system was dominated by proprietary standards and there were no strategy changes. After 2007 most sponsors changed their strategies and we observe a common pattern emerging towards open, alliance based standards endorsed by SDOs. Our interviewees confirmed that the primary reason for these changes were the decisions of Iberdrola and ERDF to develop and promote open standards. These two users, in other words, changed the rules of the standardization game in smart metering. Their impact was further amplified by the initiative of the European Commission to foster harmonized standards and by the introduction of government-driven standards in Germany and the UK.

6. Discussion

Our case has generated insights about the formation and change of institutional structures (here: technology standards) of a technological innovation system in its early years of development. At first (before 2007) standardization strategies were similar, then there was a variety of very different kinds of strategies (2007–2010), followed by a period (from 2010 onwards), in which standardization strategies became similar again. This latest shift can be interpreted as a 'meta-level' institutionalization of the technological innovation system: As markets grew, more and more actors entered the field and interactions intensified. Technology providers, complementors, SDOs, users and governments from different countries all became involved in technology development, including the formulation of standards. Increasing interaction, pursuit of different, even conflicting strategic interests and strong commitment of large users then contributed to the formation of system-wide institutional pressure: to develop alliance-based open standards with SDO involvement. Eventually, this may result in the emergence of a common, international standard for smart meter technology.

6.1. Conditions for user involvement in standardization

Users becoming standard sponsors are not very common (West, 2007; Hawkins, 1995). In many cases, they have little or no influence because they do not possess the necessary *resources and competences*. These include financial resources, technological competences (Hawkins, 1995; Bresnahan and Chopra, 1990) or the social skills to forge larger coalitions (Koehorst et al., 1999; Foray, 1994). Individual consumers and small firms are typical examples for users facing high barriers in this regard. Another reason for users not getting involved in standardization is that a technology is of limited *strategic interest* for them (Hawkins, 1995).

In the case of smart metering, we found conditions that were quite different. All three users, Enel, Iberdrola and ERDF, had a strategic interest in developing their own standard. Smart meters were central for their business (Enel) and mandated by regulation (Iberdrola, ERDF). When Enel pioneered with smart metering, no working communication technology was available yet, which is why Enel developed it from scratch. When Iberdrola and ERDF entered the field some years later, four smart meter standards were available but all of them proprietary. So they were afraid of becoming locked in.

These strategic interests are not sufficient though. In our case, the users also commanded crucial resources for standard sponsoring. All three users had both the financial and human resources to launch and sustain a standard development process. With regard to technological competences, the users had detailed insights into how the technology would be installed and what performance was required but they lacked specific competences in communication technologies, electronics, meter design or systems integration. Therefore, they had to cooperate with firms that had such complementary competences. Moreover, Iberdrola and ERDF were very successful in attracting many partners, which points to their social and political competences in terms of alliance building (cf. Garud et al., 2002).

Finally, all three user-sponsors had significant buying power as they controlled between 13 and 30 million meters. This allowed them to send strong signals in terms of future deployment prospects (expected installed base) and credible commitment (cf. Foray, 1994). From the perspective of many meter suppliers, the market shares controlled by the user-sponsors were too large to ignore, which is why they had to give up their proprietary standards. This is different from the MAP standard failure, where GM and its user partners could convince only a few technology providers to deliver compliant products, while the majority of suppliers did not follow (Dankbaar and van Tulder, 1992).

The aspect of users signaling buyer power points to the relevance of more general, system-level conditions for standardization. These include whether the interests of different users in a specific technological field are overlapping or rather fragmented (Hawkins, 1995; Dankbaar and van Tulder, 1992), whether there are firms that control large shares of the market (Dankbaar and van Tulder, 1992) and whether there is fierce competition or not (Suarez, 2004). We discuss the implications of such different constellations next.

6.2. Ideal-type settings for standardization

Our study highlights the importance of large users in standardization, next to the 'classic' situation of technology developers being influential. In line with earlier literature, we also find indications for governments playing a crucial role (Funk and Methe, 2001). Based on

Table 3
Relationship of ideal-type sub-systems (settings) and standard development processes.

	Classical setting	Government-dominated setting	User-dominated setting
Influence of user	**Marginal** (fragmented user base with little resources and know-how)	**Balanced** (governments ensure participation of all stakeholders)	**High** (small number of large users that control large shares of the market)
Influence of government	**Low**	**High** (central standardization process by gov. authority)	**Low**
Competition and standard adoption	Standards compete in the **market**; adoption characterized by bandwagon effects	Competition plays out in the standard *development process*; one **mandatory standard** for the **region** of policy influence	Standards compete in the market; **batch-wise adoption**
Mode of development	Technology providers as standard sponsors; users play hardly any role in development; all three modes	SDO mode most likely	Users play key role in standard development; Alliance and SDO mode most likely
Openness	Proprietary and open	Rather open	Rather open
Examples	VCRs, Computers; DVDs	Mobile phone or environmental standards	Mobile phone (1G), MAP, Freshcrate

our findings, we distinguish three ideal-type settings for standardization (cf. Table 3). These settings can be assumed to have an impact on how competition among standards unfolds and what kind of standards emerge.

The 'classical setting' is characterized by a large number of users (or users with fragmented interests) and little or no government intervention - in our case the Nordic countries. In such a setting, the standard battle is fought between competing technology providers each trying to establish a large base of early adopters and to win complementors that support their standard. This setting has been analyzed in most of the standardization literature (Cusumano et al., 1992; West, 2003; van den Ende et al., 2012). In the classical setting, users typically play no or just a marginal role in standard development and have little influence on the technological options made available.

In a 'government-dominated setting', standard development is driven by governmental authorities, often with the help of SDOs - in our case Germany and the UK.[6] One standard is finally made mandatory. Environmental or safety standards are often developed under such conditions (Brunsson and Jacobsson, 2000) but also technology standards have been driven by governments (Funk and Methe, 2001; Lyytinen and Fomin, 2002). In a government-dominated setting, competition among technologies plays out to the extent that technology providers vie for advantage in the committees of SDOs (Brunsson et al., 2012; Leiponen, 2008). User interests may be accommodated through committee participation.

A third type of setting is the 'user-dominated' setting. It is characterized by a few, resourceful users that control large shares of the market and governments not exerting much influence. This setting had the game changing impact in our smart meter case. User dominated settings are common in infrastructure sectors such as electricity, gas or water with utility companies serving thousands or millions of consumers and acting as central buyers of technology. But also in the oil industry, the aircraft industry, the military sector, the car industry and in telecommunication we find similar conditions (Funk and Methe, 2001; Bresnahan and Chopra, 1990; Dankbaar and van Tulder, 1992). In a user-dominated setting, technology is adopted in larger batches and users can be expected to enforce their interests already in the process of standard development.

The technological innovation system for smart meter communication can be viewed as an assembly of existing, regionally dispersed institutional structures (regulations, market structures), which over time became more and more intertwined and eventually developed some overarching coherence (the trend towards open, SDO based standards). In the case at hand, the different settings were activated sequentially. The early years of smart metering resembled a classical setting with competing proprietary standards sponsored by technology providers. Later, large users became dominant promoting open standards. In recent years, finally, also two government dominated settings added to the development of the field. While we could show that the different standards (and settings) already started to affect each other, it is yet to be seen whether this will also lead to a common standard emerging.

[6] We have to note that the influence of governments is regionally constrained, which means that we might still see competition among standards at the international level.

6.3. Limitations

Our analysis has several limitations. First, we studied a technological field in an early stage of development. This allowed us to make first hand observations but we can say little about the outcome of the standard battle: It is open which standard(s) will prevail and whether the influence of user-sponsors will last. Moreover, further internationalization might affect the field, especially with ongoing smart meter rollouts in the US and Japan.

Second, our study analyzed standardization in electricity supply, a highly regulated sector with large national differences and little competition until some years ago, when markets were (fully or partly) liberalized. While national differences enabled us to contrast different settings for standardization, sector specifics also limit the transferability of our findings.

Third, we focused very much on the few large users sponsoring and developing standards, leaving aside the many smaller users applying one or the other standard. Analyzing their strategies and rationales (e.g. to join existing alliances, to adopt a specific standard or not) will certainly be a worthwhile opportunity for further research in the field of smart grids.

7. Conclusions

Our study makes three contributions to the literature on standardization. First, we show that users becoming standard sponsors and promoting open standards may have a profound effect. In the case of smart meter technology, this very much changed the ongoing struggle over standard dominance: existing proprietary standards had to be opened up and their sponsors had to form alliances and seek support from SDOs.

Second, our analysis provides insights into the firm-level conditions for user involvement. All user-sponsors were large firms with a strategic interest in the focal technology and sufficient financial and human resources for standard development. Even more importantly, they controlled significant parts of the market. At the same time, all three users needed strategic partners to compensate for their lack of technological competences and to forge larger alliances.

Third, our findings support the distinction of three ideal-type settings for standard development. In each of these settings, standardization processes unfold differently depending on the influence users and governments can exert. Especially government- and user-dominated settings seem to be conducive for open, collaborative standardization.

With regard to the innovation systems literature, our study contributions to the larger issue of how TIS emerge and build up institutional structure over time (Markard et al., 2016). In our case, the TIS resembled a regional patchwork of different regulations and market structures. This led to fragmentation but we also observed the formation of common system-wide institutions such as the trend towards open standards. We expect similar processes of institutionalization in other domains, where institutional contexts strongly vary across regions. Examples include agriculture and biogas technology (Wirth et al., 2013), offshore wind (Wieczorek et al., 2015) or infrastructure based services more generally (Gil and Beckman, 2009).

A general pattern of TIS development may then be as follows. In early stages different socio-technical configurations co-exist without much of an impact and technology development might follow different paths (e.g. in different regions). As the technology diffuses more widely and international value-chains emerge, common structures, standards or designs emerge, thus reducing the initial differences. This is when the technology-specific institutional structures of innovation systems become fully apparent and forceful (Markard et al., 2016). Exploring such potential patterns of development is certainly a promising avenue for further research in the field of innovation studies.

Acknowledgements

This research has been part of the activities of the Swiss Competence Center for Energy Research (SCCER CREST), which is financially supported by the Swiss Commission for Technology and Innovation (CTI) under Grant No. 1155000154. The paper has benefited from the comments of three anonymous reviewers, the feedback we received at the 5th International Sustainability Transitions Conference, and many valuable suggestions by Knut Blind, Rainer Quitzow, David Seidl and our colleagues at SusTec/ETH Zurich.

References

Bergek, A., Jacobsson, S., Carlsson, B., Lindmark, S., Rickne, A., 2008. Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res. Policy 37, 407–429.
Bergek, A., Hekkert, M.P., Jacobsson, S., Markard, J., Sanden, B.A., Truffer, B., 2015. Technological innovation systems in contexts: conceptualizing contextual structures and interaction dynamics. Environ. Innov. Soc. Transit. 16, 51–64.
Bresnahan, T.F., Chopra, A., 1990. The development of the local area network market as determined by user needs. Econ. Innov. New Technol. 1, 97–110.
Brunsson, N., Jacobsson, B., 2000. A world of standards. Oxford University Press, Oxford.
Brunsson, N., Rasche, A., Seidl, D., 2012. The dynamics of standardization: three perspectives on standards in organization studies. Organ. Stud. 33, 613–632.
Colak, I., Fulli, G., Sagiroglu, S., Yesilbudak, M., Covrig, C.-F., 2015. Smart grid projects in Europe: current status, maturity and future scenarios. Appl. Energy 152, 58–70.
Covrig, C.F., Ardelean, M., Vasiljevsky, J., Mengolini, A., Fulli, G., Amoiralis, E., 2014. Smart Grid Projects Outlook 2014, in. European Union, Joint Research Centre, Luxembourg.
Cusumano, M.A., Mylonadis, Y., Rosenbloom, R.S., 1992. Strategic maneuvering and mass-market dynamics: the triumph of VHS over Beta. Bus. Hist. Rev. 66, 51–94.
Dankbaar, B., van Tulder, R., 1992. The influence of users in standardization: the case of MAP. In: Dierkes, M., Hoffmann, U. (Eds.), New Technologies at the Outset - Social Forces in the Shaping of Technological Innovations. Campus/Westview, New York.
David, P.A., 1994. Standardization policies for network technologies: the flux between freedom and order revisited. In: Hawkins, R.W., Mansell, R., Skea, J. (Eds.), Standards, Innovation and Competitiveness. Edward Elgar, Aldershot, pp. 15–35.
Depuru, S.S.S.R., Wang, L., Devabhaktuni, V., 2011. Electricity theft: overview, issues, prevention and a smart meter based approach to control theft. Energ Policy 39, 1007–1015.
Dewald, U., Truffer, B., 2012. the local sources of market formation: explaining regional growth differentials in german photovoltaic markets. Eur. Plan. Stud. 20, 397–420.
van den Ende, J., van de Kaa, G., den Uijl, S., de Vries, H.J., 2012. The paradox of standard flexibility: the effects of co-evolution between standard and interorganizational network. Organ. Stud. 33, 705–736.
Erlinghagen, S., Lichtensteiger, B., Markard, J., 2015. Smart meter communication standards in Europe - a comparison. Renew. Sustain. Energy Rev. 43, 1249–1262.
European Commission, 2009. Directive 2009/72/EC of the European Parliament and of the Council, concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. European Union (EU), European Union, Brussels.
European Commission, 2014. Benchmarking Smart Metering Deployment in the EU-27 with a Focus on Electricity (in, Brussels).
Farhangi, H., 2010. The path of the smart grid. IEEE Power Energy Mag. 8, 18–28.
Foray, D., 1994. Users, standards and the economics of coalitions and committees. Inf. Econ. Policy 6, 269–293.
Funk, J.L., Methe, D.T., 2001. Market- and committee-based mechanisms in the creation and diffusion of global industry standards: the case of mobile communication. Res. Policy 30, 589–610.
Garud, R., Jain, S., Kumaraswamy, A., 2002. Institutional entrepreneurship in the sponsorship of common technological standards: the case of Sun Microsystems and Java. Acad. Manag. J. 45, 196–214.
Gil, N., Beckman, S., 2009. Infrastructure meets business: building new bridges, mending old ones. Calif. Manag. Rev. 51, 6–29.
Hansen, T., Coenen, L., 2015. The geography of sustainability transitions: review, synthesis and reflections on an emergent research field. Environ. Innov. Soc. Transit.
Hawkins, R.W., 1995. Enhancing the user role in the development of technical standards for telecommunications. Tech. Anal. Strat. Manag. 7, 21–40.
Jain, S., 2012. Pragmatic agency in technology standards setting: the case of Ethernet. Res. Policy 41, 1643–1654.
Jakobs, K., Procter, R., Williams, R., 2001. The making of standards: looking inside the work groups. IEEE Communications Magazine, pp. 102–107.
van de Kaa, G., van den Ende, J., de Vries, H.J., van Heck, E., 2011. Factors for winning interface format battles: a review and synthesis of the literature. Technol. Forecast. Soc. Chang. 78, 1397–1411.
Koehorst, H., de Vries, H.J., Wubben, E., 1999. Standardisation of crates: lessons from the Versfust (Freshcrate) project. Supply Chain Manag. 4.
Kukk, P., Moors, E.H.M., Hekkert, M.P., 2015. The complexities in system building strategies - the case of personalized cancer medicines in England. Technol. Forecast. Soc. Chang. 98, 47–59.
Lawrence, T.B., 1999. Institutional strategy. J. Manag. 25, 161–187.
Leiponen, A.E., 2008. Competing through cooperation: the organization of standard setting in wireless telecommunications. Manag. Sci. 54, 1904–1919.
Lyytinen, K., Fomin, V.V., 2002. Achieving high momentum in the evolution of wireless infrastructures: the battle over the 1G solutions. Telecommun. Policy 26, 149–170.
Markard, J., Hoffmann, V.H., 2016. Analysis of complementarities: Framework and examples from the energy transition. Technol. Forecast. Soc. Chang. 111, 63–75.
Markard, J., Hekkert, M., Jacobsson, S., 2015. The technological innovation systems framework: response to six criticisms. Environ. Innov. Soc. Transit. 16, 76–86.
Markard, J., Wirth, S., Truffer, B., 2016. Institutional dynamics and technology legitimacy: A framework and a case study on biogas technology. Res. Policy 45, 330–344.
Musiolik, J., Markard, J., 2011. Creating and shaping innovation systems: formal networks in the innovation system for stationary fuel cells in Germany. Energ Policy 39, 1909–1922.
Musiolik, J., Markard, J., Hekkert, M., 2012. Networks and network resources in technological innovation systems: towards a conceptual framework for system building. Technol. Forecast. Soc. Chang. 79, 1032–1048.
Muzio, D., Brock, D.M., Suddaby, R., 2013. Professions and institutional change: towards an institutionalist sociology of the professions. J. Manag. Stud. 50, 699–721.
Narayanan, V.K., Chen, T., 2012. Research on technology standards: accomplishment and challenges. Res. Policy 41, 1375–1406.
Planko, J., Cramer, J.M., Chappin, M.M.H., Hekkert, M.P., 2016. Strategic collective system building to commercialize sustainability innovations. J. Clean. Prod. 112 (Part 4), 2328–2341.
Rossi, F., Bertossi, P., Gurisatti, P., Sovieni, L., 2009. Incorporating a new technology into agent-artifact space: the case of control system automation in Europe. In: Lane, D., Pumain, D., Leeuw, S.E., West, G. (Eds.), Complexity Perspectives in innOvation and Social Change. Springer Netherlands, Dordrecht, pp. 289–310.
Slager, R., Gond, J.-P., Moon, J., 2012. Standardization as institutional work: the regulatory power of a responsible investment standard. Organ. Stud. 33, 763–790.
Suarez, F.F., 2004. Battles for technological dominance: an integrative framework. Res. Policy 33, 271–286.
Timmermans, S., Epstein, S., 2010. A world of standards but not a standard world: toward a sociology of standards and standardization. Annu. Rev. Sociol. 36, 69–89.
de Vries, H.J., Verheul, H., Willemse, H., 2003. Stakeholder identification in IT standardization processes. In: King, J.L., Lyytinen, K. (Eds.), Workshop on "Standard Making: A Critical Research Frontier for Information Systems", Seattle.
Wesseling, J.H., Farla, J.C.M., Sperling, D., Hekkert, M.P., 2014. Car manufacturers' changing political strategies on the ZEV mandate. Transp. Res. Part D Transp. Environ. 33, 196–209.
West, J., 2003. How open is open enough? Melding proprietary and open source platform strategies. Res. Policy 32, 1259–1285.
West, J., 2007. The economic realities of open standards: black, white, and many shades of gray. In: Stango, V. (Ed.), Standards and Public Policy. Cambridge University Press, Cambridge, pp. 87–122.
Wieczorek, A.J., Hekkert, M.P., Coenen, L., Harmsen, R., 2015. Broadening the national focus in technological innovation system analysis: the case of offshore wind. Environ. Innov. Soc. Transit. 14, 128–148.
Wirth, S., Markard, J., Truffer, B., Rohracher, H., 2013. Informal institutions matter: professional culture and the development of biogas technology. Environ. Innov. Soc. Transit. 8, 20–41.

Jochen Markard works as a senior researcher at the Group for Sustainability and Technology at ETH Zurich. In his research, he studies the interaction of technology, actor strategies, politics and institutional structures. A focus is on new technological fields and sectoral changes, which have a potential to contribute to larger societal transformation and sustainability. Jochen approaches these issues from a range of different theoretical perspectives, including concepts from innovation studies, management and political sciences. Next to a PhD from ETH, Jochen holds degrees in electrical engineering and business administration (energy industry focus).

Sabine Erlinghagen obtained her PhD at ETH Zurich in 2014. In her thesis she investigated the origins of the "smart grid" as a new innovation system with a focus on the influence of the ICT sector. Before, she held various managerial positions at Siemens Management Consulting, Siemens IT Solutions and Landis + Gyr. Sabine holds a German Diploma in Business Administration and a French Diplôme de Grande Ecole from the University of Cologne and ESCP Europe studying at the campuses in Paris, Oxford and Berlin.

Please cite this article as: Markard, J., Erlinghagen, S., Technology users and standardization: Game changing strategies in the field of smart meter technology, Technol. Forecast. Soc. Change (2017), http://dx.doi.org/10.1016/j.techfore.2017.02.023