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Home Energy Systems - the State of the Art

Geerten van de Kaa, Andreas Ligtvoet, Theo Fens, Paulien Herder

Abstract

Smart home energy systems are technically possible to realize but are not yet applied on a large scale partly due to the fact that no common standards exist that enable interconnection of components that make up these smart energy systems. Multiple standards have been developed which are competing in standards battles. In this paper we conduct a step by step approach for the identification of these standards battles. By giving an overview of the different standards battles. This study aims to decrease uncertainty for firms and other stakeholders involved; firms may not be aware of the different standards battles that are being vied. The cases of standards battles that are arrived at in this paper may be used by academics as candidate cases for standards battles for the home energy management system and may form a point of departure for commercial stakeholders such as firms.

Keywords: smart meter; smart grid; standards; stakeholders; home energy management

Introduction

The search for a decrease in societal energy use – in the light of carbon emissions and increasing energy costs – is approached through two paths: 1) more efficient technologies and 2) more efficient behaviour. Behavioural change of stakeholders is deemed difficult and rests on the assumption that stakeholders have adequate insight in their consumption patterns and that they have tools to change these patterns.

Enter the home energy management system (HEMS). The home energy management system essentially is designed to manage the energy use in a domestic environment or in a small business environment. The HEMS may, for example, display current energy use in order to inform the owner that energy is being wasted by appliances that are not used or rooms that are heated when no one is present. Such a system may allow appliances or heating to be remotely and automatically switched on and off. It may also allow for decentrally produced energy to be sold back to the grid. Furthermore, it may reduce costs and increase efficiency by moving specific energy uses to times when the energy tariffs are low. In the future, HEMS may also take commands from the energy company, to switch off certain appliances – via so called time-of-use contracts – in order to optimise grid use.

These examples can become a practical reality on a large scale when smart grids are implemented that enable consumer electricity trading compared to the current consumer electricity procurement only. These systems provide the possibility to integrate local (decentral) production systems with the electricity grid, to charge electric vehicles, and to visualise energy use of home appliances to consumers and support energy awareness. All

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these functions may reduce the net home energy use and may reduce CO2-emissions. Energy may refer to electricity and gas. In this paper we focus solely on electricity.

An important component of the smart grid is the smart home energy system (SHES). The smart home energy system essentially is the equivalent of the local in-home smart grid. Such systems are specifically designed to manage the energy use in a domestic environment, the house, or in a small business environment such as a local store. These systems may have specific valuable outcomes. The SHES may, for example, reduce total energy use since the system allows for the activation of certain appliances, only when needed or when beneficial. Secondly it may increase comfort since appliances may automatically be turned off and on, creating for example a pleasant room temperature when needed and allowing a lower room temperature at other times. Third, it may reduce costs and increase efficiency and benefit by moving specific energy use to times when the energy tariffs are low and nationwide less energy is consumed or supply largely exceeds demand. In the future, SHES may also take commands from the energy company, either directly (IP based), or via the smart meter. For example, the energy company or the network company may take decisions as to when certain appliances are allowed to run or not at specific times via so called time-of-use contracts.

Although the home energy management systems have been technologically feasible for a long time, they are not applied on a large scale partly due to a lack of commonly accepted standards for components in the system. We focus on compatibility standards. We define a compatibility standard as: a codified specification defining the interrelations between entities (Garud & Kumaraswamy, 1993) in order to enable them to function together (H. J. De Vries, 1998). In the remainder of this paper where we use the term standard we mean a compatibility standard. A great number of applicable standards already exist for different components of the SHES and, to date, firms and others stakeholders involved have not made a decision for a common standard to enable the interconnection of different components of the SHES. The mere amount of available standards creates uncertainty for the stakeholders involved. The objective of this paper is to reach order by applying a step-by-step approach for the identification of standards for SHES.

In 2002, Den Hartog et. al. (F. Den Hartog, Uythof, & Groothuis, 2002) and, in 2009, Van de Kaa et. al. (Van de Kaa, Den Hartog, & De Vries, 2009) performed a similar study but their focus was on home networks that do not necessarily involve energy transmission. Our study builds on, and extends, Den Hartog's and Van de Kaa's studies in several ways. First, we will take into account standards that were developed from 2007 to 2013. Second, while Den Hartog and Van de Kaa focused solely on home automation we focus on SHES, the local component of the smart grid. Third, by applying a stakeholder analysis of De Vries we intend to conduct a more systematic study.

In Section 2 we will discuss the architecture around a typical SHES and we will provide definitions of the different components that make up these systems. Next, following de Vries et al (H.J. De Vries, Verheul, & Willemse, 2003) we will conduct a stakeholder analysis and we will provide an overview of the different standards organizations involved. Subsequently, for each organization we will provide the standards and categorize these standards into standards battles.

Methodology

To arrive at a full overview of different standards battles for SHES we have conducted three studies. In the first study we describe the typical architecture of a SHES. We have analyzed which technological components comprise these type of systems.

In the second study we conduct a stakeholder analysis applying the search directions offered by De Vries et. al. (H.J. De Vries, et al., 2003). This is a proven methodology that has been used in prior studies (Markus, 2006; Van de Kaa, Greeven, & van Puijenbroek, 2013) to arrive at relevant stakeholders in the standardization process. We map the stakeholders (including firms, institutions, and consumers) that are involved in the market for SHESs and analyze how they are related to each other. This can be through organizations such as alliances, consortia and committees. To identify relevant stakeholders and standards organizations, we have searched several data sources using the terms ‘Home energy management system’, ‘Home automation’, ‘Smart metering’, and ‘Smart meter’. We have searched in different sources including the Proquest database platform (including ABI/INFORM complete), the ACM digital library, the Electronics and Communications Abstracts, LexisNexis Company Dashboard, Scopus, and the internet.

In the third study, we have conducted a step-by-step approach to identify standards for SHESs by applying the method described in Van de Kaa et al. (2009). To reach a complete list of standards, we have analysed the standards that have been developed and/or are being promoted by the stakeholders found in the stakeholder analysis. Also, we have searched for standards in different databases including IEEE Standards, IHS Standards Expert, NEN Connect, Normshop, Perinorm, and the internet (using the google search engine). We have used the same search terms as used in study two. For each of the identified standards, we assess whether the standard has become successful. This results in an overview of both successful and unsuccessful standards for home energy management systems. These have been grouped into different standards wars for components of the home energy management system as identified in study 1.

Generic architecture of home energy management systems

The high level architecture of a SHES is shown in figure 1. The smart meter is the connection point to the distribution network. Note that in the case of storage and production devices this is a bidirectional connection, electricity can be extracted from the network but also be fed into the network. The SHES can be seen as an extension to the smart grid as local intelligence is entailed in this system. The SHES has two major functions: firstly to monitor energy usage and convey that to the end user by a display showing for instance the actual and historic usage of electricity and gas. Secondly, it serves as a unit to control devices, hence switching appliances on and off. One example is a smart thermostat, this component controls the heating device (e.g. a gas boiler or an electric boiler) from a predefined profile or even remotely via a smart phone.

Home energy management system

Home energy management systems (HEMS) are domestic systems that can monitor, report and influence energy use in the house. Home energy management systems (HEMS) may inform residents about their home energy use and aid in making energy efficient choices, and may even aid in the switching off and on of household appliances.

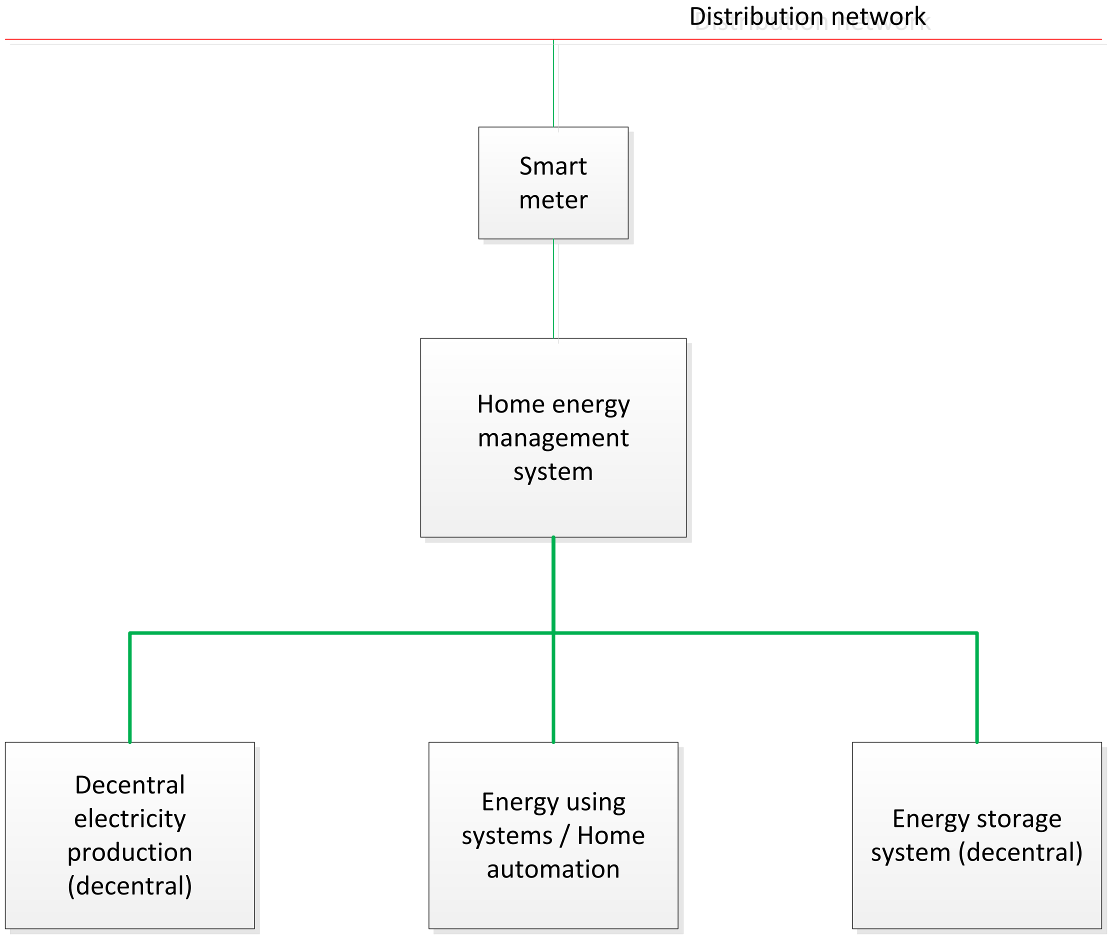

Figure 1: Architectural overview of a SHES

Decentral electricity production

The past decade showed a substantial development in small scale electricity production, known as decentrals. Next to the traditional gas or electric driven heat boiler, new systems entered the market: micro CHP systems. A micro CHP is in essence a heating boiler equipped with a device that generates electricity next to heat. Major technologies are Stirling (external combustion engines) and fuel cells. Normally these micro CHP produce electricity whenever a need arises for heat. When equipped with a heat storage buffer the device can also be operated efficiently when there is a need for electricity production. Another form of energy production that is steerable is the heat pump, mostly electricity driven. Non-steerable decentrals are Photo Voltaic (PV) solar panels and small scale wind systems. PV systems are well developed, small scale wind is still under development. Various standards are under development for decentral production systems, these are mostly market driven in which large manufacturers try to oppose their system as the standard for market reasons.

Energy storage systems

Renewable decentrals like PV, small scale wind (electricity) and solar boilers (heat) are non-steerable: the energy production is depending on weather conditions. This phenomenon is known as the intermittency effect. The consequence is that the energy has to be used at the time of production. This effect can be overcome by employing energy storage. With storage devices the actual usage moment can be decoupled from the production moment and as such the system could do away with the intermittency problem. By adding storage non-steerable production systems then become steerable. Presently this storage capacity is entering the market at acceptable economics. The main cause for this is found in developments in batteries for electric cars. Next to the car battery also stationary battery systems are now being developed. Another form of energy storage is heat/cold storage and is also fully steerable. Solar heat boilers can be used to collect heat during summer, which can be stored for usage in winter, these systems are often combined with heat pumps. In case of electricity storage systems it is observed that manufacturers of car batteries are setting the standard.

The smart meter

A smart meter can register domestic energy use on an interval basis. These devices are installed in domestic and utility dwellings. Currently some 6% of the Dutch dwellings is equipped with smart meters, with an expected growth to 80% in 2020 according to EU directives. Smart meters measure energy usage and communicate the meter readings periodically to the energy supplier via the network company, currently set at 6 times per year for actual usage notification and 1 time per year for financial settlement in the Netherlands.

The European Commission's Interpretative Note on Directive 2009/72/EC provides a description of the Commission's understanding of a smart metering system as defined by ―the ability to provide bi-directional communication between the consumer and the supplier/operator and to ―promote services that facilitate energy efficiency within the home" (p.8). A European KEMA report (Balmert, Grote, & Petrov, 2012), based on the direction taken by the debate in the European Union, for now suggests the following functionalities for a smart meter:

- "Automatic reading, processing and transmission of metering data;
- Possibility of bidirectional data communication in real-time (or with only a small time lag);
- Support of additional services and applications, e.g. home automation, remote (dis-) connection of supply or load limitation;
- Remote update of meter firmware to enable new services, communication protocols, etc." (pp.7-8)

Stakeholder analysis

The market for SHES: Converging industries

The market for SHES is highly but not fully regulated. It may be characterised as a 'quasi-market' (Bartlett & Le Grand, 1993), with transport functions in the public domain and production and delivery functions in the commercial domain.

Many different established and newly emerging industries and product markets are involved in SHESs (Baker, 2004; F. T. H. Den Hartog, Baken, N. H. G., Keyson, D. V., Kwaaitaal, J. B. B., & Snijders, W. A. M., 2004). We observe a convergence between established industries such as telecommunications, consumer electronics and home automation (domotics) with new developments in energy related industries: solar PV, micro CHP, micro wind, storage and the HEMS. The crucial link is the information technology industry, the ICT. In the energy sector the so-called IT/OT integration is seen as a major development: integrating information technology with operational technology. Given the vulnerability of the energy system and its importance for society at large, security and privacy aspects will attract the main point of attention. This puts stringent demands on HEMSs as these form the core of the energy system at end user premises.

Stakeholders

De Vries et. al. (2003) have identified 10 search directions for stakeholder identification: production chain, end users and related organizations, designers, physical systems, inspection agencies, regulators, research and consultancy, education, representative organizations, and organized groups of stakeholders. In the case of SHES, the production chain relates to stakeholders that are involved in the development of different components that are part of the SHES. In total we have collected and categorized 295 stakeholders. The list presently includes companies such as Cisco systems, IBM, Philips, Honeywell and Siemens.

End users and related organizations are the actual home owners and tenants which may be organized in local groups such as home owner associations or national groups (such as vereniging eigen huis in the Netherlands). Expert consultation revealed that consumer representation in standardization committees is rare in the Netherlands but in some countries such as the UK and Japan consumers are involved in standard development. In home energy management systems, design and production come in one hand and therefore the search directions ‘production chain’ and ‘designers’ are taken together (see 1. Production chain). One important physical system to which the different components of the home energy management system relates include the actual buildings in which the components of the SHES are implemented. Important companies include not only manufacturers but also the installation companies. Another important physical system is the smart grid itself, governed by the Distribution System Operators (DSO). Important grid operators in the Netherlands include: Alliander, Delta, Enexis, Stedin. One important inspection agency includes KEMA. Also, certification bodies such as NEN are important. Regulators (ACM Energiekamer) and policy makers (ministries EZ) are involved heavily in the smart meter component of the HEMS partly due to the privacy issues that surround smart metering. For example, the Dutch senate has rejected a law establishing the installation of smart meters recently, which was the cause for a two year delay in large scale rollout of smart metering. Universities, research institutes and consultants play an important and major role in standardization for HEMS in the Netherlands. Amongst others important stakeholders include IT consultancy firms. The Education search category is less relevant for the identification of stakeholders for HEMS. Although a lot of universities are actively engaged in research relating to smart grids active participation in standardization is rare. Representative organizations include consumer organizations such as the consumer’s union (consumentenbond). In table 1 an overview of a sample of the different stakeholders is presented. The full list is available upon request.

Production chain	Cisco systems, IBM, Philips, Honeywell, Siemens, etc.
End users and related organizations	Vereniging eigen huis, consumentenbond
Designers	See production chain
Physical system	RoyalHaskoning-DHV, Alliander, Delta, Enexis, Stedin, Nuon, Eneco, etc.
Inspection agency	KEMA, NEN
Regulators and policy makers	ACM Energiekamer, policy maker EZ
Research and consultancy	IT consultancy firms
Education	n/a
Representative organizations	Consumentenbond

Table 1. sample of stakeholders for different search directions applying De Vries et. al (H.J. De Vries, et al., 2003)

Networks of stakeholders

The stakeholders mentioned in section 4.2 are members of various formal standards organizations and consortia. The full list of standards organizations is available upon request. This section describes the most prominent ones.

Formal standardization organizations include ISO or IEC, their national members such as ANSI, BSI, and AFNOR, and regional standards-development organizations related to these national members (for instance CEN, CENELEC, ETSI, or ITU). Most standardization organizations have different work groups which develop standards for particular product markets and or technical areas. The International Organization for Standardization (ISO) is a global network that develops standards with involvement of the sectors that will put them to use. 149 countries are involved in the organization. ISO cooperates closely with the International Electrotechnical Commission (IEC), a non-profit organization established in 1906. The IEC is responsible for standardization of electrical equipment. The American Institute of Electrical Engineers (AIEE) and the institute of Radio Engineers (IRE) merged in 1963 into the Institute of Electrical and Electronics Engineers (IEEE) which develops electrical and IT standards. The European Committee for Electrotechnical Standardization (Cenelec) is a non-profit technical organization created in 1973. The organization prepares voluntary electrotechnical standards.

Konnex Association
ZigBee Alliance
Salutation Consortium
Echonet Consortium
Smart meter standardisation
Fiber To The Home Council
The Digital Living Network Alliance
Smart grids European Technology Platform
M 441 Smart Metering Mandate
M 490 Smart Grid Mandate
Open Meter Project
NIST smart grid mandate
IEC smart grid (SMB strategic group)
IEEE Smart grid initiatives

Table 2. a sample of standards organizations active in home energy management systems

Various consortia exist that develop and/or promote standards for components of the SHES. Also, we take into account sectoral standardization organizations, governmental standardization organizations and professional standardization organizations. In table 2 an overview is presented of the consortia.

Standards for smart home energy systems

For each of the standards organizations found in study 2 we have analyzed the standards that they are developing or promoting. Also, we have searched for standards following the approach as sketched in Section 2. In the appendix (table 3) we present an overview of the standards that were found for different components of the SHES. The standards are both national and international standards and include successful and unsuccessful standards.

First, we observe that a lot of standards have been developed for different components of the SHES. Many standards battles are currently being fought and, to date, for none of the components one single common standard exists. We also observe that within the category energy using systems / home automation systems the number of standards per standards battle is high. This can partly be explained by the fact that many different stakeholders originating from different industries are involved and these all want to push their standard to the market. The fact that there are so many standards that co-exist increases uncertainty for stakeholders that have to make a decision for a standard.

We observe that for some components of the SHES (such as the smart meter), standards are mostly developed in committees whereas for other components (such as the subcomponents under the component energy using systems / home automation systems) the standards are mostly developed in consortia. In the Netherlands, the standardization process for smart meters can best be characterized as a committee based standardization process whereby the regulator plays an important role whereas for energy using systems / home automation systems the standardization process can best be described as a market based standardization process. Standardisation literature tends to distinguish between ‘committees’ and ‘markets’ to solve coordination problems (Farrell & Saloner, 1988). In the former, stakeholders agree on a common standard, whereas in the latter, different companies or consortia propose their own specifications that compete for market dominance. From the stakeholder analysis it can be observed that, in the area of SHES, a combination of these modes exists, and also a significant role for the government is apparent.

Discussion and conclusion

In this paper we have conducted a step by step approach for the identification of stakeholders involved in and standards battles for SHESs. By giving an overview of the different standards battles, this study aims to decrease uncertainty for firms and other stakeholder involved; firms may not be aware of the different standards battles that are being vied.

We have not found dominant standards for (the components of) the SHES. One of the reasons for the lack of dominant standards could lie in the fact that the current market design and its underlying institutional arrangements are not equipped to facilitate and support the transition towards a SHES. An interesting area for further research is to evaluate which institutional arrangements are the most effective for facilitating the development, selection and use of standards of SHESs.

The cases of standards battles that are arrived at in this paper may be used by academics as candidate cases for standards battles for the SHES. For example, scholars interested in studying factors for standard dominance could study historical cases of standards battles in a comparative case study (Yin, 2009) and attempt to explain their outcomes using factors for standard dominance. Currently, one of the novel areas in research on standards battles relates to responsible innovation whereby concepts from responsible innovation are applied to standardization (Van de Kaa, 2013). Here, it is proposed that standards should be developed according to the principles of value sensitive design (Friedman, 1996; Van den Hoven, Van de Poel, & Vermaas, forthcoming). These scholars argue that during its development and after its realization, a standard should be flexible to facilitate changes related to ethical and societal values surrounding the technology (such as privacy, security, and reliability). This may increase the acceptability and thus the market uptake of the standard. Future research could further explore this notion by focusing on different standards battles identified in this paper. Then, standards battles should be chosen for components which are surrounded by ethical and societal values. Expert consultation revealed that, in that respect, three cases identified in this paper are especially interesting: smart meters, wireless home automation and wired home automation. These components are surrounded by different values such as privacy, security and reliability.

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Component	Subcomponent	Competing standards
Smart meter		
	Smart meter	NTA 8130, DRMS X.X, DLMS, IEC 62056-21, NEN-EN 13757, IEEE Std 1901, IEEE P1703, IEEE 1377, DLMS/COSEM standard (IEC 62056 / EN 13757-1), IEEE Std 802.15.4, Wired M-Bus, M-Bus protocol(EN 13757), 6LoWPAN
Decentral electricity production systems		
	Solar photovoltaics	multi-crystalline silicon, mono-crystalline silicon , cadmium telluride, copper indium (gallium) selenide, amorphous silicon , thin film organic
	Small wind mills	DIN EN 61400-25-4, AGMA 6006-A03
	micro CHPs	
Energy using systems / Home automation systems		
	Wired Local Area Networks (application level)	Arcnet vs ATM vs CEPCA vs Ethernet vs FDDI vs Home plug and play vs homeplug vs hiperlan2 vs open air vs Passport vs Powerpacket, Smart Energy Profile 2
	Wired Local Area Networks (infrastructure level)	FRF vs MPLS/Framerelay vs Orthogonal frequency divising multiplexing vs Salutation vs SSERQ vs Token Bus vs Token Ring vs UPA
	Wireless Local Area Networks (infrastructure level)	EWC vs HomeRF vs IEEE802.16 vs Open air vs IEEE802.11
	Wireless personal area network	Bluetooth vs IEEE 802.15.3 vs IEEE 802.15.4 vs Irda vs Zigbee
	Home networks	DLNA vs HANA vs HAVi vs HomeAPI vs HOMAPNA vs Moca vs UPnP, IEC/TS 62654, NEN-ISO/IEC 15045-1, ISO/IEC 14543-3-7, IEC 61970, IEEE 1905.1, ITU-T G.9960
	Home automation (wired and wireless)	AHAM vs CEA851 vs CEBus vs Echonet vs EHS vs HBS vs HES vs HGI vs HomeCNA vs HomeGate vs HPnP vs Lontalk vs Smarthouse, ISO/IEC 14543KNX, zigbee
	Building automation	BACnet vs BatiBUS vs COBA vs DALI/IEC 60929 vs FND vs Instabus vs KONNEX vs Metasys vs MOCA vs Profibus vs Worldfip vs X10 vs Zigbee, NPR-CLC/TR 50491-6-3 , NEN-EN 13321-1, NEN-EN 15232, ISO 16484-5
	Mobile telecommunications	3G vs Dect vs GPRS vs GSM vs UMTS
	Consumer electronics	Displayport vs DVI vs HDMI vs Scart vs VESA vs VGA
	Computer networks	(wireless) USB vs Convergence bus vs Firewire vs IRDA
	Smart thermostat	Eneco Toon vs Essent e-thermostaat vs Nuon e-manager, Aurum, Honeywell
Energy storage systems		
	heat/cold storage	NEN-EN-IEC 60531, NEN-EN-IEC 60379
	electric stationary storage batteries	J537, 1679-2010 IEEE
	electric car batteries	SAE J2847, SAE J2836/1-3, SAE : J2931/5

Table 3. Groups of standards for components of the SHES

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