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A battle over smart standards: Compatibility, governance, and innovation in home energy management systems and smart meters in the Netherlands

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ABSTRACT

In recent years, awareness and concern about global warming from fossil fuels have notably grown. This process of global warming can, in part, be circumvented by the usage of renewable energy technology in homes. Two protocols exist that can realize wireless communications between sensors and electrical appliances on the one hand and the smart meter (which connects to a visual interface) on the other hand; Zigbee and Z-Wave. When one of these protocols is chosen, a home energy management system can be realized, allowing monitoring of the devices that consume energy in the home. There is no standard, and these two communication protocols are in a battle for dominance. This paper aims to find which factors could affect the outcome of this standards war in the Netherlands, and determine which protocol has more chances to achieve dominance. The factors that were determined as most important are compatibility, big fish, current installed base, and complementary goods, whereas, counterintuitively, technology superiority is one of the least relevant factors. It appears that Zigbee has a higher chance to achieve dominance. The paper concludes by discussing these results in light of the standardization literature.

1. Introduction

Concerns related to climate change and the gradual decrease of natural resources have dramatically increased in recent years. To prevent further worsening of this situation, renewable and sustainable energy technologies have been developed. For example, homeowners can now install solar panels and heat pumps and gradually make their homes fully energy-autonomous and remove them from the electricity grid. An essential first step is to own a smart meter. Approximately 80 percent of the population in North America is expected to have a smart meter by the year 2024 [1].

In addition to owning a smart meter, consumers should invest in renewable energy generating systems and energy-efficient appliances. Ideally, the consumer should have an overview of how much energy each appliance uses and what the associated costs are. This could result in lower consumption or in the choice to have consumption take place during off-peak hours instead of peak hours. Monitoring the energy consumption of appliances is possible by implementing a home energy management system (HEMS). Implementation of these devices will provide information about, e.g., energy usage to users [2], which might influence the behavior of users so that they use energy more efficiently [3]. This paper focuses on these types of systems.

HEMS can be defined as a technological system consisting of a combination of systems that generate and use energy interconnected to a smart meter to monitor the energy generation and usage of the devices in the home. An interface should be established between the smart meter on the one hand and the electrical appliances on the other hand to realize such a system. While several companies, including Samsung, Amazon, and Panasonic, have launched their HEMS, each of these systems uses one particular protocol to realize that connection; either the interface standard Z-Wave or Zigbee [4]. These are typical examples of 'smart standards', those defining interconnectivity within or between smart systems (in this case, a HEMS). Also, various companies such as General Electric and Honeywell use either the Z-Wave or the Zigbee protocol [5].

All ingredients for a fierce and long-lasting standards battle appear to be present. Stakeholders disagree on standards [6], and two consortia, the Z-Wave Alliance and the Zigbee Alliance have developed two competing standards and attempt to enlist (consumer electronics) companies into their network. This paper addresses the question of what

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is the importance of factors for standard dominance for HEMS and which standard will have the highest chance of achieving dominance according to experts. It focuses on the connection between electronic equipment and the smart meter. The research was performed in the Netherlands.

This is not the first standards battle that occurs in history. For example, at the end of the 2000s Blu-ray and HD DVD were battling to set the standard for blue laser DVDs [7,8]. Until the establishment of Blu-ray as the dominant standard, most consumers were reluctant to choose for one or the other standard because of uncertainty about which standard will achieve dominance. When consumers want to realize a HEMS, they have to decide between a system based on Z-Wave or Zigbee. Both consumers and companies might postpone this decision until a choice has been made for one common standard by either actor. This scenario is not preferable because it could postpone the realization of smart HEMS and make energy-neutral homes less accessible.

The paper's objective is to contribute to the theory on de-facto standardization and dominant designs by determining the weight of factors for standard dominance for the connection between the smart meter and the appliances according to experts by employing the best worst method (BWM). The paper thus provides additional empirical evidence that the outcome of the standards battle can be explained. The paper aims to generate new theory on factors for standard dominance for energy systems.

The study is innovative in various ways. First, research on standards battles mainly focuses on battles for the information technology, telecommunications, and consumer electronics industries [7,9–12]. Few scholars focus on standards battles for energy systems (an exception is [13]). This study looks specifically at standards battles for energy systems and evaluates which factors are especially relevant to those types of systems. More specifically, it focuses on the battle between standards for the connection between the smart meter and appliances, a case that has not been studied before. Second, the study includes the opinions of a set of experts who are difficult to access; that can be seen as a contribution [14]. Third, the paper provides empirical evidence as to which factors are important in the fourth phase of the technology dominance process established by Suarez. Fourth, the paper provides insights into which factors should be influenced by companies or public policy makers to ensure that certain standards become successful if that wish were present.

The remainder of the paper starts with presenting an overview of the theoretical perspectives towards standard dominance. Subsequently, the methodology will be presented, followed by the results and a discussion and conclusion.

2. Theory

In the past, many different researchers have looked at the question of how and why standards become dominant [9,15–21]. Starting in the 1970s, scholars that focus on technology and innovation management study how specific dominant designs of products come about [22]. They emphasize that due to a series of events that might be path-dependent, certain products look a certain way. By choosing to implement specific changes in the design, users can even become locked into a design that may not be the technologically superior one [23]. These researchers have an ex-post way of looking at how dominant technology arises in markets as they mainly explain the outcome of standards battles afterward [20].

Some researchers take an ex-ante way of approaching the topic, arguing that companies can execute specific strategies and thus ensure that their technology becomes successful [17,18,20,24]. They emphasize the importance of amassing many users of the technology (installed base) [19,25]. This can be accomplished by, e.g., penetration pricing (pricing below cost) [26] or organizing large marketing campaigns to influence expected or perceived installed base [27]. Also, the installed base can be increased by introducing new versions of the standard. For example, the Zigbee Alliance recently launched the All Hubs Initiative, making it easier to develop products based on their standard. This could result in a larger number of companies opting for the standard. This was also the case in the battle between Blu-ray and HD DVD. With every change in the standards, more companies from different industries opted for the standards [8]. Other scholars have focused on what affects consumers' intention to adopt technology [28]. Specifically, for HEMS, scholars have mentioned the existence of subsidies or the extent to which consumers can save money by adopting the systems [29].

When it comes to achieving dominance of technology, a distinction can be made between 5 stages [20]. The first stage starts with a company or research institution that initiates applied research related to the technology. When companies or research institutes have developed a first prototype, the second phase starts. When a saleable product is launched, the third phase starts, and if there is an early frontrunner, the fourth phase starts. The fifth phase starts when a dominant standard has been reached. In that phase, competition occurs based on that dominant standard. Other scholars build upon notions such as network externalities to explain standard dominance. Industrial and network economists put forth these notions in the mid-1980s [26,30]. These effects relate to the increase of economic value consumers experience when more technologies are being sold to other consumers (as consumers can interact with more consumers). One example of such technology is a mobile phone. With the introduction of ICT in the energy industry (resulting in, e.g., the smart grid), network externalities may also become visible. Then, fierce standards battles may be fought, a phenomenon that can now be observed for the standards battle studied in this paper. From the former, it can be concluded that the theoretical emphasis of the field standardization is hybrid [14] as these researchers emphasize that standards emerge as a result of market mechanisms, policies, and strategies of individual firms.

3. Home energy management systems

The paper focuses on standards that establish the connection between sensors and electrical appliances on the one hand and the smart meter (which connects to a visual interface) on the other hand. The two wireless technologies of Zigbee and Z-Wave are early front runners and the focus of this paper lies on these two standards.

Zigbee is an open wireless networking protocol built on top of IEEE 802.15.4 [31] that facilitates creating a personal area network. In 1998, the protocol's development was initiated and was standardized by the Zigbee Alliance in 2003. Some of the firms that adopt Zigbee in their products are Amazon, Philips, Ikea, Apple, and Google. Z-Wave is a proprietary wireless protocol to establish home area networks for home automation appliances. In 1999, Z-Wave was developed, and in 2001 it was released by its inventor, ZenSys Corp. In 2005, five large companies formed the Z-Wave Alliance to make their products interoperable [32]. Amongst others, companies that implement the standard in their products include Honeywell, Logitech, Bosch, Motorola, and Cisco. Table 1 provides an overview of both standards.

From Table 1, we can conclude that Zigbee and Z-Wave have already built up an installed base and various products (in the form of electronic appliances and smart meters) are available that make use of one of these standards. The number of certified products is 2500 for Zigbee and 2400 for Z-Wave. One can thus clearly conclude that the battle between the two standards is in the fourth stage of the technology dominance process, the decisive stage [20], and companies are attempting to increase the installed base. Furthermore, on some technical aspects such as network topology, security, and level of openness, the standards are similar. In many aspects, Zigbee appears to be technologically superior compared to Z-Wave. For example, Zigbee has more application areas, is more energy-efficient, can guarantee higher data transfer speeds, and can connect more devices in one network. However, the range of Z-Wave is higher than that of Zigbee.

Table 1
Technological characteristics of the standards (as adopted from [33–36]).

	Zigbee	Z-Wave
Devices connected in one network	Up to 65,000	Up to 232
Certified products (2021)	2500	2400
Supporting companies	400	700
Communication mode	RF	RF
Frequency	915 MHz and 2.4 GHz	918/960 MHz
Network topology	Mesh	Mesh
Data transfer speed	20–250 kb/s	9.6–100 kb/s
Range	10 m	30 m
Security (encryption	128 bit AES	128 bit AES
Energy usage	Medium	High
Type of standard	Open	Open
Primary markets	Industrial automation, research, home automation, telecommunications, healthcare	Home automation

4. Methodology

The paper applies a qualitative research method (combining document analysis and semi-structured interviews) to answer the research question. First, the relevant criteria (factors for standard dominance) were searched. The secondary sources that report on this battle were analyzed, and it was determined which standard dominance factors were referred to in these sources. Next, three experts (that had full knowledge of the two standards) were interviewed using an open-ended questionnaire. Factors are relevant if they are mentioned in the literature or by one of the three experts. This procedure guarantees that all relevant factors are taken into account. Next, a multi-criteria decision-making method was applied to provide weights to the relevant factors. Here, five experts were interviewed. Table 2 presents an overview of the characteristics of the experts that participated in the study. As the location of the research was the Netherlands, primarily dutch experts were interviewed. Experts 1, 2, and 4 have participated in the first part, while all experts have participated in the multi-criteria decision-making method interviews. To decide whether somebody can be considered an expert, we used three criteria mentioned by Shanteau et al. [37]; experience in terms of the number of years that the expert has worked in a relevant job, certification in terms of the highest degree obtained, and the internal consistency of answers that were given. The first two criteria are included in Table 2.

4.1. Best worst method

To arrive at criteria weights, the linear model version of the Best Worst Method (BWM) [38,39] was applied. The reason that we have chosen the BWM is threefold; first, by using that approach, fewer evaluations are needed compared to other approaches such as Analytic Hierarchy Process (AHP); second, the obtained factor weights are very reliable. Third, the overall consistency of the comparisons is higher than for other methods based on full matrices [38,39]. The method has been successfully used in similar cases and for other decision problems [40]. The BWM consists of the following five steps:

Step 1

Determine the relevant criteria $\{c_1, c_2, \cdots, c_n\}$. The procedure is described above.

Table 2
Interviewee details.

#	Background	Current function	Years of experience	Degree
1	Industry/ Academia	Associate partner; senior researcher	50	Dr.
2	Academia	Full professor	18	Dr.
3	Academia	Full professor	39	Dr.
4	Academia	PhD candidate	12	M.Sc.
5	Academia	Associate professor	30	Dr.

Step 2

Determine the best and the worst criterion. After this step it becomes clear which factor for standard dominance is seen as the most important one and which factor is seen as the least important one according to the experts.

Step 3

Using pairwise comparisons, determine how much less important the other criteria are compared to the most important criterion. The scores vary between 1 (equally important) and 9 (extremely less important). This exercise result in the Best-to-Others vector:

$$A_B = (a_{B1}, a_{B2} a_{Bn})$$

where

a_{Bj} refers to the preference of the best criterion B over the criterion j.

Step 4

Using pairwise comparisons, determine how much more important the other criteria (except the best one) are compared to the least important criterion. The scores vary between 1 (equally important) and 9 (extremely more important). This exercise result in the Others-to-worst vector:

$$A_W = (a_{1W}, a_{2W} a_{nW})^T$$

Where

a_{jW} refers to the preference of j over the worst criterion W.

Step 5

Determine the optimal weights of the factors for standard dominance. In order to find these weights the following problem should be solved:

$$\min \xi^L$$

s.t.

$$|w_B - a_{Bj} w_j| \leq \xi^L, \; for \; all \; j$$

$$|w_j - a_{jw} w_W| \leq \xi^L, \; for \; all \; j$$

$$\sum_j w_j = 1$$

$$w_j \geq 0, \; for \; all \; j$$

This linear programming problem can be solved with simple optimization tools resulting in a unique solution of optimal weights ($w_1{}^*$, $w_2{}^*, \cdots, w_n{}^*$) and the consistency ratio ξ^* which should be as close to zero as possible to have high consistency. For more details concerning each step's design principles and significance, we refer to Rezaei [38,39].

Once the weights are found, each of the communication protocols can be evaluated to each criterion. The overall value is then calculated as follows:

$$Value_{Technologyi} = \sum_j w_j^* T_{ij}$$

W^*_j represents the optimal weight for criterion j, and T_{ij}, represents the evaluation of technology i on criterion j. Expert 1 assessed how well each of the communication standards performs to find the value of the communication protocol for each of the criteria. The expert provided a number from 1 to 3, meaning 1 ($T_{ij} = 1$) that it performs poorly, 2($T_{ij} = 2$) it has a moderate performance and 3($T_{ij} = 3$) that it performs well.

5. Results

Nine factors for standard dominance appeared to be relevant after consulting with the literature and interviewing the three experts; compatibility, flexibility, current installed base, network externalities, switching costs, complementary goods, technological superiority, big fish and regulator. These factors are defined and elucidated in Table 3.

The BWM results are presented in Table 4. The consistency ratio (ξ^*)results are shown in the last row of Table 4. All the results obtained show a good consistency ratio, and therefore the data are considered reliable, and these values provide additional insurance that the interviewees are experts [37].

The results in Table 4 show that, according to the experts, compatibility (average weight of 0.21) is the most important factor. This factor has been mentioned in the literature to be of importance, but, then, it primarily refers to backwards compatibility (compatibility with a previous generation) [41]. For example, it has been important to achieve standard success in the video gaming industry, where video gaming consoles are often made backward compatible with the previous generation video games. For example, the PlayStation 2 console was backward compatible with various games initially made for the PlayStation console. This was one of the reasons why PlayStation 2 was the winner in the sixth generation video gaming console standards battle as it could tap into the existing installed base of users of the previous console version [9,11]. In our case, compatibility refers to horizontal compatibility. Its importance can be explained in the following way. The more the standard can guarantee horizontal compatibility, the more devices can be interconnected through the standard, increasing the user value of the HEMS in which the standard is incorporated. Prior research has also shown that increased interoperability positively affects social acceptance of HEMS technology in China [42]. As one respondent noted about one of the standards: "Zigbee is a mesh protocol, which means that you can add devices and connect with each other, so you have the advantage of a network of devices talking to each other […] you don't want to go by the router, you want to have direct communication." Z-Wave is also a mesh protocol so applying that protocol provides the same advantage.

According to the experts, the second most important factor is the existence of a big fish (average weight of 0.15). One respondent noted: "if a big company with power and influence puts new devices into the market that support a certain communication protocol, then it influences the choice of other manufacturers on supporting that same communication protocol" which is reflected in the number of complementary goods. In this battle, Amazon is one of the big fishes that supports Zigbee. This acted as a signal for other companies which followed Amazon and adopted the standard in their products. So, it appears that hooking up with a (reputable) big fish may increase the availability of complementary goods as it can act as a signal for other smaller companies to adopt the focal standard.

According to the experts, installed base and complementary goods are the third and fourth most important factors with average weights of 0.14 and 0.12. In the literature, these two factors have also been mentioned as crucial factors for standard dominance, and often in relation to each other [18]. Various scholars have argued that the two factors are interrelated [18,25]. As more installed base is accrued for a particular product that incorporates a standard, more manufacturers of complementary goods will choose to develop complementary goods for that standard. Furthermore, when more complementary goods are available that utilize a standard, consumers will choose to buy a technology that utilizes that standard. This mechanism also played a role in the high definition video format battle [7]. The more DVD titles were available for a specific blue laser DVD player, the more people adopted that DVD player, and the more people adopted that DVD player, the more the movie studios chose to bring out titles specifically for that DVD player. This also plays a role in the case that is studied in the current paper. The more electronic devices are available that incorporate a

Table 3
Relevant factors.

Factor	Definition and elucidation
Technological superiority	According to the literature, a standard is technologically superior if it has a higher technological performance than the competitors [24].
Compatibility	According to the standardization literature, this factor "concerns the fitting of interrelated entities with each other so that they can function together" [21]. In HEMS, the interrelated entities refer to the electrical components and the smart meter in the home. A HEMS must connect with as many of such devices as possible. Therefore, the horizontal compatibility that the standard guarantees is crucial for its success in the market.
Flexibility	Flexibility refers to the extent to which a standard can be changed to changing user requirements. Given the high pace of technological change in the energy sector, this factor is highly relevant.
Complementary goods	This factor refers to a technology used in conjunction with another good or service. Under the influence of indirect network externalities, the value of a core technology in which a particular standard is implemented depends upon the number of complementary goods (products) in which that same standard is implemented. For example, the more energy-generating devices installed in a home that apply one particular standard, the higher the value of a HEMS that implements the same standard.
Regulator	The regulator refers to the governmental agency that may enforce a standard on the market [24].
Big fish	This factor refers to a large company or regulatory agency that en masse supports a standard [24]. This can create instant dominance for that standard.
Current installed base	The current installed base of a technology refers to the number of times that units in which the standard is implemented are sold and used by consumers. Under the influence of network externalities, this positively influences the chances that other users will adopt that technology. The higher the installed base, the higher the (network externality) value as more users can be reached through the technological interface.
Network externalities	Network externalities refer to either direct or indirect network externalities. Direct network externalities refer to the phenomenon whereby connected technological components increase in value the more they are being used in a network. For example, when a telephone is used by only one person its value accruing from direct network externalities is zero. However, when more people use other similar phones they can call each other and the value accruing from direct network externalities will increase. Indirect network externalities refer to the phenomenon whereby technology increases in value the more complementary goods are available for that technology. For example, when more applications (complementary goods), such as WhatsApp, are available for an operating system (core technology) such as android or iOS, the value of that operating system to users will increase as they can make use of more applications. For HEMS, indirect network effects are relevant. This works as follows. A particular standard is used in the smart meter and energy monitoring interface available to users. If that same standard is used in more electronic devices and sensors in the home (complementary goods), the value of the core technology increases.
Switching costs	This refers to the costs needed to change from one technology to competing technology.

Table 4
Weights determined with experts' data.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Average
Technological superiority	0.05	0.11	0.06	0.07	0.08	0.07
Compatibility	0.06	0.26	0.31	0.22	0.20	0.21
Complementary goods	0.13	0.11	0.14	0.14	0.10	0.12
Flexibility	0.13	0.08	0.08	0.14	0.03	0.09
Current installed base	0.31	0.11	0.14	0.09	0.06	0.14
Big fish	0.06	0.17	0.14	0.07	0.32	0.15
Regulator	0.05	0.02	0.06	0.14	0.07	0.07
Network externalities	0.19	0.08	0.06	0.14	0.06	0.10
Switching costs	0.03	0.06	0.02	0.02	0.10	0.04
ξ*Expert	0.07	0.07	0.10	0.05	0.08	

certain standard, the more people will adopt a HEMS system that incorporates that standard, and the more of these HEMS systems are installed in homes, the more manufacturers will choose to develop products that utilize the standard that is incorporated in that HEMS system.

The battle analyzed in this paper is positioned in the dominance process' fourth stage. According to Suarez, installed base, network effects, complementary assets and switching costs are especially important in that stage. Our results partly confirm his arguments as installed base, and network effects are considered important by the experts. However, the experts find the characteristics of the standard supporters not to be relevant at this stage. Furthermore, experts rate both technological superiority and regulator among the three least important factors. This could be because the battle is not located in the dominance process' early stages, where these factors are crucial [20].

The assessment of how well each of the communication standards performed on each of the factors can be found in Table 5. Zigbee received the highest overall score of 2.34 against a score of 1.78 for Z-Wave. Therefore, expert 1 believes that Zigbee has the highest chance of achieving success.

6. Discussion and conclusion

HEMS can help monitor energy generation and usage in homes and thus indirectly help reduce unneeded carbon emissions. However, to realize these systems, standards are needed that establish the interface between the smart meter and the appliances. When one dominant standard is reached, a HEMS can be realized. It has been shown that many people are concerned about costs associated with HEMS [43,44]. Dominant standards can reduce costs of HEMS in the long term meaning that the chances increase that they become adopted by more people, eventually leading to a higher degree of energy efficiency in more homes. Zigbee and Z-Wave are competing for market dominance, and this paper studied factors for their success. Relevant factors were distilled from the literature and by consulting with experts. Weights were assigned to the factors by applying the BWM. Five experts found (horizontal) compatibility to be the most important factor affecting the emergence of a dominant standard, and they believed Zigbee to have the highest chance of achieving success.

6.1. Theoretical contributions

Several contributions can be distinguished. First, this is novel in that it focuses on standards battles in the energy sector. The focus on this sector is innovative as the existing literature on standards battles mainly focuses on the IT and telecommunications sector, and this literature explicitly calls for more research on factors for standard dominance in other sectors [20]. Furthermore, the existing relevant literature on HEMS primarily focuses on factors affecting consumer intention to adopt that technology [29]. Our research provides the factors for standard dominance relevant to the case under investigation and presents their weights according to experts.

Some scholars have focused on another standards battle for a component of the HEMS; the connection between the database and the smart meter [13]. They concluded that the most important factors are flexibility, technology superiority, and compatibility. According to our experts, this study finds partial support for these previous results in that compatibility is a crucial factor. However, the experts also found the availability of complementary goods and the current installed base to be of importance. This study thereby adds to our understanding of the factors of standard dominance for components of the smart grid, and, more particularly the HEMS by (1) confirming previous research and (2) offering two new factors for standard dominance for this particular system. More generally it can be argued that, according to the experts, standard dominance factors relevant and important for standards battles in the IT and telecommunications industries (installed base, compatibility, complementary goods) also appear to be relevant and important in the energy sector.

Few experts are knowledgeable in this area, and they are reluctant to share their opinion - including their opinion can be considered a contribution on its own [14]. Furthermore, this is one of the first studies that empirically studies the importance of factors for standard dominance in the fourth stage of the technology dominance process as defined by Suarez [20]. Suarez argues that in that phase the most

Table 5
Ranking of alternatives.

	Zigbee			Z-WAVE		
	Value	Weight	Weighted score	Value	Weight	Weighted score
Technological superiority	3	0.07	0.22	1	0.07	0.07
Compatibility	2	0.21	0.42	2	0.21	0.42
Complementary goods	3	0.12	0.36	2	0.12	0.24
Flexibility	2	0.09	0.18	2	0.09	0.18
Current installed base	2	0.14	0.28	2	0.14	0.28
Big fish	3	0.15	0.45	1	0.15	0.15
Regulator	2	0.07	0.13	2	0.07	0.13
Network externalities	2	0.10	0.21	2	0.10	0.21
Switching costs	2	0.04	0.09	2	0.04	0.09
Total			2.34			1.78

important factors are 'operational supremacy', 'brand reputation and credibility', 'network effects', 'installed base', and 'switching costs'. Some of these factors appeared to be relevant in the current study, with the current installed base being the third most important and network effects the fifth most important factor. However, various factors that were found to be important were not considered by Suarez in the fourth phase of the technology dominance process. These factors include compatibility and availability of complementary goods. Therefore, this study contributes to the literature by providing additional relevant factors in the fourth stage of the dominance process. Furthermore, Suarez mentions that complementary assets and the bandwagon effect are important in the fourth stage while these factors are considered either irrelevant or unimportant by our experts.

6.2. Practical implications

This research is of advantage for managers and policymakers as it provides them with the factors they could influence to increase the chances that standards achieve dominance. Results show that Zigbee has a higher performance score than Z-Wave in three criteria; technological superiority, complementary goods, and big fish.

When firms would improve the extent to which the Z-Wave protocol is horizontally compatible, and the technological superiority would also be changed, this could change the outcome. For example, let us assume that there would be a score of 1 for both technological superiority and compatibility for the Zigbee protocol. Furthermore, there would be a score of 3 for the Z-wave protocol for these factors. The total weighted score would then be 1,99 for Zigbee and 2,13 for Z-wave. Firms that promote Z-wave could establish a favorable position by improving these factors. A recommendation following from this exercise is that to overcome the dominant position of Zigbee, the alliance behind Z-Wave should try to focus on developing more complementary goods and improving its technological superiority over Zigbee.

Other possibilities can easily be explored by changing the numbers presented in Table 5. Managers are encouraged to do that exercise as it may further their understanding of factors for standard dominance. That exercise could, e.g., lead to the insight that managers should attempt to identify a big fish in this market and hook up with that party, increasing the value of big fish for the Z-wave protocol.

6.3. Limitations and future research recommendations

This study is limited in four ways. First, we have interviewed a total of five experts. The paper focuses on a particular technology meaning that few experts are present. We want to highlight that the current five experts are among the top experts in this area, so their opinion matters. Second, the paper studies one particular form of technology battle, the one in which standards compete against each other. However, more forms of technology battles (including battles for a dominant design or dominant platforms) exist. Also, the focus of this study is limited to the energy domain. Finally, the study focuses on the fourth stage of the technology dominance process as defined by Suarez. Future research could interview other experts and focus on other types of technology battles in other domains, and they could focus on other stages of the technology dominance process. By conducting that future research, we can arrive at more insights, arrive at a better understanding concerning factors for standard dominance, and assess the generalizability of our findings.

The results of this paper point to Zigbee as the standard with the highest chance of achieving dominance. However, other standards are gaining relevance in the HEMS contexts. At the time of writing, these do not threaten Zigbee or Z-Wave as they are currently used for other purposes. Nevertheless, as this is a fast-changing environment, this can change in the future, presenting a different scenario in which these standards could challenge the existing standards. Studying these new battles that could then emerge could be an exciting area for future research.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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