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van de Kaa, Geerten; Kamp, Linda

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Exploring design dominance in early stages of the dominance process: The case of airborne wind energy

Geerten van de Kaa *, Linda Kamp

Delft University of Technology, Jaffalaan 5, Delft, 2600, GA, the Netherlands

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ABSTRACT

This paper is about Airborne Wind Energy Systems, a promising new wind power generating system that, although technologically possible to realize, is not available on the market yet. Currently, many different technological options for the systems are being developed. One question for such systems is where to position the generator, on the ground or in the air. These two configurations constitute two alternative designs that may eventually characterize the dominant design. This paper aims to find which of the two alternative design choices will have the highest chance to dominate and what factors affect that. The literature on these two design options is consulted, and indicators are distilled. Experts are asked to evaluate these indicators making use of the Best Worst Method. It appears that for this battle, technological superiority, flexibility, the regulator, and 'big fish' are the most critical factors. In part, this supports earlier thinking in dominant design research and offers new insights into that literature. The two designs are found to have still equal chances of achieving design dominance. This paper is novel in that it applies the Best Worst Method to Airborne Wind Energy Systems for the first time, and, for one of the first times, empirically studies factors for technology dominance in the stage at which a prototype is ready, but a commercial product has not been launched yet.

1. Introduction

Wind power has been used by society to generate electricity since relatively recently. As the wind speed increases with altitude (Vogelmann et al., 2015), it makes sense to utilize the high layers of the atmosphere where wind power is the greatest. Therefore, recently, various technologies to capture wind energy at high altitudes have been developed. When these Airborne Wind Energy Systems, also called High Altitude Wind Energy systems, are realized, this will result in a new form of renewable electricity production, which can contribute to cleaner production in industry. However, a single dominant design has not yet emerged for Airborne Wind Energy Systems, inhibiting advancements in this new renewable energy sector. This paper aims to look for factors that affect the establishment of dominant designs in this sector.

Airborne Wind Energy Systems convert the kinetic energy of strong winds at high altitudes to electricity (Cherubini et al., 2015). Thus, the system operates at much higher altitudes than conventional wind turbines. Two configurations are under development; (1) 'Fly-Gen systems' which consist of a group of tethered rotorcrafts that generate the electricity in the sky which is transferred through electric cables to a ground station, and (2) 'Ground-Gen systems' whereby kites, gliders or wings generate power in the sky and the conversion to electricity takes place on the ground (Cherubini et al., 2015).

Suarez (2004) argues that the process that leads to dominant designs, also called a 'technology battle' or a 'standards battle', can be subdivided into different stages. The first stage, technology buildup, starts when scientists and companies research the technology. In this case, the first patent for a Fly-Gen system was already issued in 1981 (Loyd, 1981), while the first patents were issued for the Ground-Gen systems in the early 2000s; Ippolito (2006) issued the patent 'vertical axis wind turbine with control system steering kites' in 2006 and the patent 'System and process for automatically controlling the flight of power wing airfoils' in 2007 (Ippolito, 2007).

The second stage, technical feasibility, starts when the first prototype of the new technology is ready, whereas the third stage starts with launching the first commercial product. As various prototypes have been developed for Airborne Wind Energy Systems, but commercial products are not yet available, the technology battle for this technology can be positioned in the second stage of the Suarez' model.

The main question of this paper is: *According to experts, which*

* Corresponding author.
E-mail address: g.vandekaa@tudelft.nl (G. van de Kaa).

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Airborne Wind Energy System design, Fly-Gen or Ground-Gen, will have the highest chance of achieving dominance, and what is the importance of the underlying factors that influence that a design becomes dominant in the second stage of the dominance process?

This research question will be answered by following a multi-criteria decision-making approach: the Best Worst Method (BWM) which was developed in 2015 (Rezaei, 2015) and refined in 2016 (Rezaei, 2016). Factors for standard dominance will be applied to the case of standards battles for Airborne Wind Energy Systems. A similar approach was followed in previous research to assign weights to factors for standard success for smart meters (Van de Kaa et al., 2019) and energy storage (Van de Kaa et al., 2019b). Three contributions of this paper can be distinguished:

- It is the first time that this particular approach is applied to the case of Airborne Wind Energy Systems. It can thus be seen as a replication study in a unique new context.
- It is also the first time that the importance of factors for design dominance are studied specifically for energy technology in the second stage of Suarez' technology dominance model.
- The research contributes to previous studies with the ultimate underlying goal of establishing weights for factors for standard dominance for different arenas and in different stages of the dominance process. This will benefit researchers, managers, and public policy makers as the uncertainty surrounding the decision for the standard to be chosen will decrease.

A detailed description of the methodology will follow in section 2. The factors used in the analysis of the case will be described in section 3, literature review. In section 4, the results will follow. The paper concludes with a discussion in section 5 and a conclusion in section 6.

2. Methodology

A two-phase approach is applied to determine which design will have the highest chance of achieving dominance and what is the importance of the underlying factors influencing that design reaching dominance. A similar approach was used to determine weights for standard success factors' weights for data exchange protocols (Van de Kaa et al., 2018) and wind turbine designs (Van de Kaa et al., 2020). In the first phase, relevant factors that affect the chances that a design reaches dominance in this industry are determined by interviewing two experts and studying literature that has reported on this case. This literature includes a master thesis on kite-based airborne wind energy technologies (Doe, 2015), a European commission report on its commercialization (Van Hussen et al., 2018), and a scoping study on related specific incentive schemes (Petrick, 2018). A factor is considered relevant when mentioned either by at least one expert or in at least one of the consulted literature sources. Relevant factors found for this case are underlined in section 3 of this paper. In the second phase of the approach, the relevant factors are ranked for importance by applying a multi-criteria decision-making approach; the BWM. For this part of the analysis, six experts were interviewed. Short backgrounds of the interviewees are included in Table 1. Experts 2 and 7 have participated in phase 1 of the study, while experts 1 to 6 have participated in phase 2 of the study.

The BWM consists of five steps:

Step 1: Defining a list of criteria $\{c_1, c_2, \ldots, c_n\}$. These criteria are the relevant factors for design dominance that came out of phase 1 of the analysis.

Step 2: Determining the best and worst criterion; the experts determined the most and least important factor for design dominance for this case.

Table 1
Characteristics of the respondents.

	Background	Position	Expertise and years of experience
1.	Academia	Associate Professor	Diffusion of radical innovation, amongst others kite-based Airborne Wind Energy Systems. Over 30 years of experience.
2.	Industry	Technical manager Airborne Wind Energy company	Aerospace and marine applications composite structures, automation of composite production, and Airborne Wind Energy. Over 15 years of experience.
3.	Industry/ Academia	CEO and co-founder of an Airborne Wind Energy company	Kite power. Over five years of experience.
4.	Academia	Assistant Professor	Socio-technical analysis of development and implementation of sustainable energy technologies. Over 20 years of experience
5.	Academia	Researcher	Airborne wind energy, kite power systems. Over five years of experience
6	Industry/ Academia	Researcher	Multidisciplinary system design, safety and cost optimization of Airborne Wind Energy systems. Over five years of experience
7.	Industry/ Academia	Co-founder Airborne Wind Energy startup/ Professor	Airborne Wind Energy, kite power generation. Over 30 years' experience

Step 3: Comparing the best criterion over other criteria through a number lying between 1 and 9[1], resulting in the best-to-others vector:

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

Here, a_{Bj} refers to the preference for the best criterion B over criterion j.

Step 4: comparing the preference for the other criteria to the worst criterion through a number between 1 and 9 resulting in the others-to-worst vector:

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

where

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

Step 5: Discovery of the optimal factor weights, which is accomplished by solving the following problem:

$$\begin{aligned} &\min \xi^L \\ &s.t. \\ &|w_B - a_{Bj} w_j| \le \xi^L, \ for\ all\ j \\ &|w_j - a_{jw} w_W| \le \xi^L, \ for\ all\ j \\ &\sum_j w_j = 1 \\ &w_j \ge 0, \ for\ all\ j \end{aligned}$$

The solution to this problem is unique and consists of the optimal weights $(w_1^*, w_2^*, \ldots, w_n^*)$ and the consistency ratio ξ^*. The closer this ratio is to zero, the higher the level of consistency of the model.

Experts were also asked to evaluate each of the two generator designs (Fly-Gen and Ground-gen) concerning each criterion. Finally, this equation was used to calculate the overall values of each technology:

[1] When experts assign a score of 1 they believe that the factor is ranked equally important as the other factor while assigning a score of 9 means that the expert would evaluate the factor extremely more or less important than the other factor.

$$Value_{Technology\ i} = \sum_j w_j^* T_{ij} \quad (3)$$

w_j^* shows the optimal weight of criterion j and T_{ij} shows the evaluation of technology i concerning criterion j, which can take on four values. 0 represents a non-relevant factor. If a technology performs weakly on the factor, it is assigned a score of 3. If it performs moderately, it is given a score of 5; if it scores well, it is given a score of 7.

3. Factors for design dominance

Various researchers have studied standards battles and factors that affect the outcome of these battles. These scholars have drawn upon economic, management, and standardization research and have created various frameworks explaining standard dominance. In the remainder of this paper, we will apply the framework developed by Van de Kaa et al. (2011), who have subdivided factors for design dominance into five categories. In Table 2, the categories are shown. In the first column, the category is mentioned, the second column explains that category, whereas the third column provides the underlying factors that will be taken into account in the remainder of this paper. The remainder of this section will explain these factors in detail. As already mentioned, the factors that were found to be relevant for Airborne Wind Energy Systems are underlined in the text.

Various scholars have paid attention to the question of what factors affect the emergence of dominant designs. Tushman and Anderson (1986) introduce the notion of technological discontinuities which start a process of experimentation of variation leading eventually to a dominant design. According to Utterback and Suarez (1993), that design is a result of choices that are made both with respect to the technology and in the market. Economists have argued that various markets that tend to converge to single designs or standards are often affected by market mechanisms such as path dependencies that firms cannot influence directly (Liebowitz and Margolis, 1995). Another market mechanism is the rate of change in the market. When it is high, the uncertainty in that market will increase, and the likelihood that technology will become dominant will decrease (Smit and Pistorius, 1998). Also, network externalities (a phenomenon introduced by Farrell and Saloner (1985) and by Katz and Shapiro (1985) make designs supported by more consumers more attractive to other consumers because of more networking opportunities. This is one of the main reasons for the success of the early telephones and fax machines. A bandwagon effect may start above a certain threshold, resulting in situations in which consumers get locked into specific designs (De Vries, 1999). When such a situation occurs, switching costs will become high, resulting in a situation in which consumers may be locked into a design that is not the 'best' one (David, 1985). For example, the layout of our keyboards' keys is arranged following the QWERTY format, which is challenging to learn. However, because the switching costs are high, people will not switch to better alternatives such as the DVORAK layout (David, 1985).

Table 2
Categories and factors for design dominance.

Category	Explanation	Factors
Characteristics of the format supporter	The technology supporters' complementary assets and resources that are needed to compete in a battle for design dominance	Financial strength, Brand reputation and credibility, Operational supremacy, Learning orientation
Characteristics of the format	Technological aspects of the design that make that design outcompete other designs	Technological superiority, Compatibility, Complementary goods, Flexibility
Format support strategy	The technology supporters' strategic maneuvering that are needed to compete in the battle for design dominance.	Appropriability strategy, Timing of entry, Marketing communication, Pre-emption of scarce assets, Commitment
Other stakeholders	Stakeholders other than the technology supporter that may affect the outcome of the battle for design dominance.	Previous installed base, Big Fish, Regulator, Network of stakeholders
Market characteristics	Characteristics in the market that indirectly affect a technology's chances of achieving market dominance.	Bandwagon effect, Network externalities, Rate of change, Switching costs

Management scholars argue that companies can apply strategic maneuvering in markets affected by network effects and directly influence their outcomes (Suarez, 2004). These scholars argue that to affect the success of designs the focus should be on the number of people that adopt particular design options and how to influence that so-called 'installed base' (Shapiro and Varian, 1999). Early timing of entry can result in 'preemption of scarce assets', which both affect the installed base positively (Lieberman and Montgomery, 1988). Although firms that engage in standardization may attempt to include their patented technological proposals and increase the total price of the standard, they may also choose to follow an 'open systems strategy' (Garud and Kumaraswamy, 1993), whereby the price is kept to a minimum. This appropriability strategy led to the success of many standards, including SUN's JAVA programming software (Garud and Kumaraswamy, 1993). Firms may also apply various forms of marketing communications to affect the subjective components of value that consumers attach to the technology (Schilling, 2020). For example, new generations of gaming consoles are often pre-announced at the consumer electronics show. As a result, the expected installed base of such products increases. When consumers believe that technology will reach a dominant position in the market, they will prefer that technology over competing technologies. The availability of complementary goods can increase the installed base even further (Schilling, 1998). This is also the case for the gaming console industry; when a new gaming console is introduced, it often comes combined with highly ranked complementary goods in the form of video games (Gallagher and Park, 2002). Finally, it has been shown in some cases that commitment towards the technology can be of importance in establishing market dominance (Van de Kaa et al., 2011). Large firms have many conflicting agendas, which can be detrimental to the overall commitment towards the technology, which is one aspect that can negatively influence its chances of success (Van de Kaa and De Vries, 2015).

Of course, the strategies mentioned above can only be successfully applied when the firm possesses the required resources (Gallagher and Park, 2002). To enter the market or engage in expensive marketing campaigns, a firm needs sufficient financial strength. As expectations among consumers are essential aspects that determine which design will achieve success, brand reputation and credibility of firms are also essential resources for emerging as the winner of a technology battle (Shapiro and Varian, 1999). Finally, when demand for a technology increases, operational supremacy in production capacity might be needed to adhere to this rising demand (Van de Kaa et al., 2011). Also, a firm may have been involved in a technology battle in a previous generation. When that firm can better learn from earlier mistakes (learning orientation) it is in a more favorable position than its competitors (Klepper and Simons, 2000).

Both economists and management scholars have focused on the phenomenon of de-facto standardization. Although a dominant standard is not entirely comparable to a dominant design (Gallagher, 2007), the establishment of dominant standards is similar. Therefore, we argue that literature on factors affecting the establishment of dominant standards can also be applied to our case. Standards can gain market dominance when the regulator enforces them on the market (Axelrod et al., 1995). A big and powerful entity such as a government may also en masse adopt a standard and as such act as a 'big fish' (Suarez and Utterback, 1995). As a result, the standard may instantly reach dominance. Standardization scholars mainly focus on technical aspects of the standard, such as the technological superiority of the standard over competing standards. Although this is certainly not a sufficient condition for success, as the case of QWERTY vs. DVORAK demonstrates (David, 1985), it can help in establishing dominance as consumers favor designs that are technologically superior in terms of, e.g., aesthetics or ease of use.

Researchers also emphasize that standards' chances of reaching success might be increased by adhering to a larger flexibility (referring to the number of times that new specifications are released). They argue that the more versions are released, the higher the chance that the standard reaches a dominant position in the market as more firms will adopt the standard (Van den Ende et al., 2012). It may also increase the diversity within the network of stakeholders that supports the standard (Van den Ende et al., 2012). Researchers also emphasize the importance of compatibility and argue that a technology that is made backwards compatible with previous generations has a favorable position (Lee et al., 2003) as it can tap into the existing previous installed base.

4. Results

In phase 1 of the research, 21 factors were found to be relevant for this case. These were underlined and explained in the previous section. The remainder of this section presents the results of phase 2 of the research, in which the relevant factors are ranked for importance by applying the BWM. An essential step of the BWM is to calculate the consistency of the answers given in the interviews with the experts. This is done by determining the consistency ratios. In Table 3, the consistency ratios that resulted from phase 2 of the research are presented; these numbers show good consistency results.

Table 4 provides the weights for the relevant factors according to the experts. This provides a first indication of which factors are relevant in the second stage of the dominance process. It appears that experts rank technological superiority as especially important (global average weight: 0.166). This is in line with the argumentation of Suarez (2004). In the second stage, although prototypes have been developed, commercial products have not yet been introduced. Then, it is still possible to reach dominance solely through offering a technologically superior design. In fact, some Airborne Wind Energy entrepreneurs are still working on improving their first prototypes.

Additionally, experts see an essential role for the regulator in this stage of the dominance process (global average weight: 0.080). That stakeholder could enforce a specific design on the market resulting in instant standard dominance or support a particular design by way of specific policy measures. Experts rate this factor as important, which is not surprising as it was also argued for by Suarez (2004). Energy could be produced more cost-effectively by this technology than with 'normal' wind turbine technologies, and the technology can be implemented in areas where wind turbines cannot be implemented. These are two reasons why institutions like the European Union are interested in supporting the technology. Secondly, because the Airborne Wind Energy technology is a new technology, regulations regarding its airspace use are not lucid yet. Therefore, the regulator's role can be important when new regulations are established for this technology regarding airspace use: it can provide specific regulations that may either support or hinder the technology. As one expert mentioned: "One of the main points is the regulation of the airspace because we are neither an aircraft, nor a wind turbine nor a high building."

Experts found some factors important for this case that are not mentioned in the prior literature on design dominance in the early stages of the dominance process (Suarez, 2004). For example, flexibility is ranked high (global average weight: 0.105), which intuitively makes sense. In this early stage of the technology dominance process, experimentation is key to effective entrepreneurship (Kerr et al., 2014). It is in this stage that entrepreneurs present their prototypes to the general audience. It is important that the prototypes can be changed so that the feedback that might be received at, e.g., startup or entrepreneur events can immediately be incorporated. Firms that can do so easily and quickly might have an advantage over firms that have to follow more cumbersome processes. Apparently, flexibility is an important factor for design dominance before the first commercial product arrives on the market.

Also, experts point towards the importance of the existence of a 'big fish' that might en masse adopt a certain design (global average weight: 0.078). Airborne Wind Energy Systems may become part of large energy infrastructures. These infrastructures are characterized by the existence of a small number of large energy companies. If one of these companies chooses to adopt one type of Airborne Wind Energy System exclusively, that system might reach instant dominance. This might occur even before a first commercial product is launched. The 'big fish' could also be interpreted as the venture capitalist that provides funds to the entrepreneur. For the type of system that we focus on in this research, other companies outside the energy market might provide funds. For example, one of the former companies in this market was an alphabet company for several years.

Table 5 presents the final part of the research; the ranking of the two alternative designs. It appears that both the Ground-Gen systems and the Fly-Gen systems still have an equal chance of achieving dominance. However, this might be because of the fact that the technology is in an early stage of development. It might be the case that when commercial products enter the market, a battle between the two designs (and, maybe, others) might arise after all. Alternatively, it may be the case that the third stage will never commence, and commercialization is never reached.

When concentrating on the four important factors for Airborne Wind Energy Systems, most of them have similar values for both types of generators. However, it appears that the four experts find the underlying design of the Ground-Gen systems more flexible. This is one reason why the Ground-Gen system has a slight advantage compared to the Fly-Gen systems.

Table 3
Consistency ratio results.

	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6
Categories	0.107	0.085	0.127	0.085	0.063	0.071
Characteristics of the format supporter	0.036	0.222	0.143	0.021	0.088	0.154
Characteristics of the format	0.151	0.159	0.092	0.077	0.128	0.095
Format support strategy	0.071	0.187	0.092	0.104	0.091	0.077
Other stakeholders	0.107	0.132	0.027	0.032	0.124	0.036
Market characteristics	0.091	0.222	0.126	0.032	0.133	0.054

5. Conclusion and discussion

5.1. Answer to the research question

To answer the research question about the main factors that affect the emergence of a dominant design for Airborne Wind Energy Systems in the second stage of the technology dominance process, primary and secondary data analysis were combined to find relevant determinants for technology dominance for this case. Furthermore, experts were asked to assign weights to the factors by applying the BWM. The emergence of a dominant design for Airborne Wind Energy Systems is found to be affected by twenty-one factors, of which four factors appear to be especially important; technological superiority, flexibility, regulator and 'big fish'. Both Fly-Gen and Ground-Gen systems still have an equal chance to become the dominant design in this market.

Table 4
Local and global average weights.

Categories and Factors	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Local average weight	Global average weight
Characteristics of the format supporter	**0.240**	**0.158**	**0.107**	**0.059**	**0.125**	**0.214**	**0.150**	
Financial Strength	0.393	0.167	0.265	0.447	0.500	0.423	0.366	0.055
Brand reputation and credibility	0.071	0.056	0.082	0.234	0.294	0.192	0.155	0.023
Operational Supremacy	0.107	0.611	0.388	0.085	0.059	0.115	0.228	0.034
Learning orientation	0.429	0.167	0.265	0.234	0.147	0.269	0.252	0.038
Characteristics of the format	**0.373**	**0.158**	**0.407**	**0.381**	**0.438**	**0.357**	**0.352**	
Technological superiority	0.528	0.337	0.487	0.385	0.609	0.476	0.470	0.166
Compatibility	0.075	0.051	0.145	0.231	0.092	0.095	0.115	0.040
Complementary goods	0.170	0.096	0.079	0.154	0.053	0.143	0.116	0.041
Flexibility	0.226	0.516	0.289	0.231	0.246	0.286	0.299	0.105
Format support strategy	**0.067**	**0.236**	**0.220**	**0.093**	**0.125**	**0.143**	**0.147**	
Appropriability strategy	0.061	0.140	0.342	0.087	0.135	0.096	0.143	0.021
Timing of entry	0.378	0.514	0.392	0.157	0.448	0.269	0.360	0.053
Marketing communications	0.112	0.140	0.108	0.365	0.270	0.173	0.195	0.029
Pre-emption of scarce assets	0.224	0.065	0.050	0.235	0.040	0.115	0.122	0.018
Commitment	0.224	0.140	0.108	0.157	0.108	0.346	0.181	0.027
Other stakeholders	**0.160**	**0.388**	**0.047**	**0.233**	**0.250**	**0.214**	**0.215**	
Previous installed base	0.060	0.046	0.297	0.129	0.052	0.060	0.107	0.023
Big Fish	0.286	0.362	0.324	0.226	0.591	0.398	0.364	0.078
Regulator	0.464	0.493	0.324	0.419	0.119	0.398	0.370	0.080
Network of stakeholders	0.190	0.099	0.054	0.226	0.238	0.145	0.159	0.034
Market characteristics	**0.160**	**0.061**	**0.220**	**0.233**	**0.063**	**0.071**	**0.135**	
Bandwagon effect	0.273	0.611	0.369	0.226	0.570	0.149	0.366	0.049
Network externalities	0.091	0.056	0.417	0.226	0.055	0.392	0.206	0.028
Rate of change	0.182	0.167	0.165	0.129	0.141	0.392	0.196	0.026
Switching costs	0.455	0.167	0.049	0.419	0.234	0.068	0.232	0.031

Table 5
Ranking of alternatives.

	Ground-Gen systems							Fly-Gen systems						
	Performance score						Weighted score	Performance score						Weighted score
	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6		Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	
Characteristics of the format supporter														
Financial Strength	3	5	5	3	3	7	0.211	3	7	5	3	3	5	0.211
Brand reputation and credibility	3	7	3	3	5	5	0.088	3	7	3	3	5	5	0.088
Operational Supremacy	3	7	3	3	3	7	0.149	5	5	3	3	3	5	0.138
Learning orientation	0	7	5	5	7	7	0.177	0	5	5	5	5	7	0.154
Characteristics of the format														
Technological superiority	3	5	3	5	7	7	0.824	5	7	3	3	5	3	0.714
Compatibility	5	5	5	3	3	7	0.195	5	5	5	3	3	5	0.181
Complementary goods	0	5	5	3	3	5	0.136	0	5	3	3	3	3	0.110
Flexibility	5	7	5	5	7	7	0.636	3	3	5	5	5	3	0.424
Format support strategy														
Appropriability strategy	5	7	3	3	5	7	0.113	5	3	3	3	7	7	0.106
Timing of entry	5	7	5	3	7	5	0.299	5	5	5	3	5	7	0.280
Marketing communications	5	7	3	3	5	7	0.148	3	3	3	3	7	7	0.128
Pre-emption of scarce assets	5	5	5	3	3	5	0.079	3	7	5	3	3	5	0.079
Commitment	0	7	5	3	5	5	0.091	0	5	5	3	5	5	0.084
Other stakeholders														
Previous installed base	3	5	3	3	3	3	0.084	3	7	3	3	3	3	0.092
Big Fish	3	7	5	3	5	7	0.385	5	7	5	3	3	5	0.360
Regulator	3	7	5	3	3	5	0.340	3	5	5	3	3	5	0.314
Network of stakeholders	3	7	5	3	5	7	0.174	5	5	5	3	5	3	0.151
Market characteristics														
Bandwagon effect	3	7	5	3	7	7	0.322	5	3	3	3	5	3	0.221
Network externalities	5	5	5	3	3	7	0.116	5	5	5	3	3	3	0.099
Rate of change	5	7	5	3	5	5	0.115	5	5	5	3	3	3	0.092
Switching costs	5	7	5	3	5	5	0.195	5	3	5	3	5	5	0.169
Total							4.876							4.195

5.2. Limitations

This paper has some limitations. One limitation is that we only interviewed seven experts. This technology is in the early stages of development which inherently results in less experts being available. However, the seven experts are among the top experts in this area so their opinion matters. Furthermore, the paper has a specific focus, the second stage of the dominance process, and the conclusions thus only apply to that stage. Also, we have focused on the energy sector and one particular case, Airborne Wind Energy Systems. Therefore, our conclusions are only applicable to that specific case.

5.3. Theoretical contributions and recommendations for future research

We add to the literature on dominant designs by applying factors for design dominance to one of the possible future sustainable energy technologies: Airborne Wind Energy Systems. We contribute to the bourgeoning empirical literature that attempts to assign importance weights to factors for technology dominance for different technological arenas. This study is replicating the prior argumentation put forth by Schilling and Suarez who argue that firms can influence the chances that certain technologies achieve market dominance. While Schilling (1998) focuses on specific factors such as timing of entry strategies, Suarez (2004) offers a framework consisting of multiple factors. The study also replicates empirical results in the context of smart meter connectivity (Van de Kaa et al., 2019), energy storage (Van de Kaa et al., 2019), and energy conversion (Van de Kaa et al., 2017) that point towards the notion that the outcome of technology battles can be modeled. Additionally, it is the first time that factors for technology dominance are applied to Airborne Wind Energy Systems.

More specifically, whereas most literature on dominant designs focuses on the period between the first commercial product introduction and establishment of a dominant design, few scholars focus on the period before a first commercial product has been introduced. For one of the first times, this paper presents empirical research on the second stage of the dominance process. It appears that for this particular battle for design dominance, experts agree with the factors pointed out by Suarez as being important in the early stages of the dominance process as they point towards the importance of technological superiority and the regulator. However, they also point to other factors, including flexibility and the existence of a 'big fish'. Thus, Suarez's argumentation can partly be verified, but other factors are also found to be important.

Currently, for the more established energy technologies such as wind turbines and solar panels dominant designs have already been established and their efficiency have improved and implementation costs are getting lower over time. Companies find it difficult to enter the market and compete with these established designs. One expert noted: "Wind and solar are getting cheaper, which means we also have to go cheaper and cheaper. So we have to see if we can compete against those technologies." Airborne Wind Energy Systems need to outperform conventional wind turbines on multiple levels to flourish in such a market. Perhaps the Fly-Gen and the Ground-Gen systems will eventually coexist in the market together with other sustainable energy technologies as they can be used for different applications and in different kinds of locations. The sustainable energy market is complex, and within the market, there may be multiple sub-markets where each technology can have its own protected space or niche. For example, in 2019, a company demonstrated an Airborne Wind Energy system for offshore purposes. In addition, one respondent explained that while other companies are aiming for the big market and for directly selling a Megawatt system, his company aims for a niche market that can be reached more quickly. As he comments: "while learning, we will get experience and slowly go to the big market." Another respondent noted: "We are mainly focusing on the small-scale niche market and trying to scale it up step by step."

Future research could look into other aspects that determine the dominant design of Airborne Wind Energy Systems, such as the flight operation mode or rigid wings versus soft wings. Secondly, future research could study more battles for design dominance in or outside of the energy sector using the same approach and focus on the first stages of the dominance process to reach a complete picture of which resources and strategies are needed by the startups and entrepreneurs active at this stage. For example, they can focus on the stage before a prototype is ready or after a commercial product is launched but an early front runner has not yet emerged. Thirdly, future research could be done into the obstacles for Airborne Wind Energy Systems' large-scale diffusion, or strategies companies could employ to get through the difficult second stage of technology development and launch their first commercial product successfully onto the market.

5.4. Concluding remarks

One solution to accomplish one of the grand challenges of our times about a cleaner supply of energy could be to harness wind at high altitudes. Airborne Wind Energy Systems can be a solution here, but prices remain high and commercial systems have not been realized yet. One of the reasons for this is that there is no dominant design yet. When a dominant design is established, within design competition can occur, which can drive down costs. The outcome of this paper points to four factors that, according to the experts that we have interviewed, affect the emergence of a dominant design in this market: technological superiority, regulator, flexibility and 'big fish'. This finding contributes to the scientific field and provides entrepreneurs, managers of large companies, and public policymakers with an insight into what is especially important to focus on in this stage and which factors they should act upon. When this knowledge is appropriately applied, we hope this will bring us one step further towards a dominant design and, ultimately, large-scale implementation of these systems.

CRediT authorship contribution statement

Geerten van de Kaa: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization. **Linda Kamp:** Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing, Visualization.

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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