Chapter 7
Financing Strategies for Airborne Wind Energy

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Abstract The development and large-scale application of new technology will be a central element to meet the current challenges of the global energy system, such as accelerating climate change, concerns about future energy security, limited global energy access or deteriorating balances of payments. At the same time, the restructuring of the energy system has to happen at reasonable cost. Airborne wind energy (AWE) can play an important role in contributing to meet this challenge. Yet, despite the large potential of AWE, further financing will be required to establish commercial viability of the technology and enable its large-scale deployment. Drawing on the most recent literature as well as on a range of qualitative interviews among both CEOs of AWE companies and risk capital investors the article characterizes AWE from a financing perspective and sheds light on the potential barriers for attaining substantial risk capital. An understanding and the active management of the identified investment barriers offer AWE companies important toeholds to develop their financing strategies. Potential implications and current strategies in the industry are discussed in the article.

7.1 Introduction

The need for a fundamental restructuring of the global energy system is ever more evident. Increasing environmental limitations namely climate change call for action. But also concerns about future energy security and deteriorating balances of payments render the search for sustainable energy alternatives essential. As of today, the vast majority of 80% of the global electricity production is based on coal, natural

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gas and nuclear power plants. However, investments into renewable energy technology have recently increased substantially. In 2011 global investments have reached USD 257bn, up from only USD 39bn in 2004 [4]. Net investments into clean energy capacity even exceeded those into conventional fossil fuel-based generation capacity. Though these are important developments, data from the International Energy Agency [13] shows that the increasing share of renewable energy capacity has come along with soaring levels of subsidies. Subsidies accounted for USD 88bn in 2011 and are expected to rise to USD 240bn in 2035 if existing policies are maintained and already announced commitments are implemented.

Against this figure and amid growing concerns about the cost of extensive subsidies for renewable energy following the global financial crisis and the Euro crisis, the need for considerable cost reductions and a higher competitiveness of renewable energy generation becomes more and more obvious. Airborne Wind Energy (AWE) as a radical renewable energy technology innovation promises large economic and environmental benefits. Building on established technology components and expected low generation cost, AWE could become an abundant, cheap and environmental friendly source of energy available in most parts of the world. At the same time, however, the large potential of AWE is matched by large financing requirements to develop the technology and prove its commercial viability.

Considering the importance of financing for the further development of AWE, this article shall illustrate potential strategies for AWE companies in securing additional funding. For this purpose a broad literature review on the financing of technology innovations in the renewable energy sector has been conducted and complemented by a telephone survey among the most important actors in the industry including both AWE companies and investors.

To begin with, Sect. 7.2 will illustrate the financing of AWE according to the lifecycle theory of the firm, which will include a description of distinct development stages as well as common types of financing available at each stage. Based on the classification of AWE in the technology life cycle, Sect. 7.3 will provide an indepth analysis of the most prominent financing constraints and current challenges of AWE in attracting funding. Section 7.4 will conclude illustrating the current funding structure of AWE companies as well as potential funding sources and promising financing strategies to access them.

7.2 Financing AWE along the Technology Life Cycle

A large body of literature has described the general constraints for the financing of innovations[1]. Among a variety of imperfections on the capital market particularly high information asymmetries in the principal-agent relationship between innovator

[1] Compare Hall [10] for a good overview of the general challenges for the financing of innovations. Additional information on the relationship between the funding for R&D activities, the company age and size and the source of funding can be obtained from Himmelberg and Petersen [12] and Müller and Zimmermann [22].

and investor make it difficult to attain sufficient funding. Brown et al. [2] show that this is particularly true for startup companies in high technology industries, which are often exclusively founded for the development of a particular technology and can often only rely on external risk-seeking equity. Due to adverse selection as described by Akerlof [1], it is especially good startups which are suffering from higher costs of capital.

Despite the broad consensus on the constraints for the financing of technology innovations such as AWE, these may not be misunderstood as a static condition. Instead, innovations describe a dynamic process involving several distinct stages of development. As one of the first to describe this process, Penrose [25] established the life cycle theory of the firm, which has been further elaborated and adapted several times (Steinmetz [32]; Hanks et al. [11]). Although the theory originally describes the development of a firm over its life-time, it can also illustrate the development of new technologies driven by small high-tech startups whose business is closely linked with the development of a specific technology. This is particularly true for the initial stages of the process. However, the life cycle development including the definition of development stages and time periods in between can significantly differ among industries and technologies. Figure 7.1 shall illustrate a typical technology life cycle for innovations in the renewable energy sector.

Each development stage is characterized by different challenges, capital requirements and risks and successful funding over the whole technology life cycle will require different sources of financing and the involvement of different types of investors with particular investment strategies [36]. Examining the technology life cycle of AWE more closely will be important to identify the specific financing challenges and constraints and to develop appropriate financing strategies, which are tailored to meet both the requirements of AWE companies as well as of potential investors.

7.2.1 Basic Technology Research

Basic technology research describes the first step of the innovation process. Typically, basic research produces knowledge of fundamental principles and facts, which are normally published and become public goods after their discovery but do not grant their discoverer exclusive rights over the discovery. Basic research efforts are therefore normally not undertaken by private enterprises but are instead conducted at universities and other public research institutions. In case of AWE, basic research has been and is conducted at various universities worldwide in all relevant fields from the assessment of the global resource potential for AWE over the calculation, evaluation and simulation of the potential for specific kite systems to control mechanisms and the development of first prototypes. This at least in part publicly funded research has shown the general feasibility of AWE as well as the large potential of the energy of high altitude winds. Basic research has thus laid an important foundation for the emerging AWE industry.

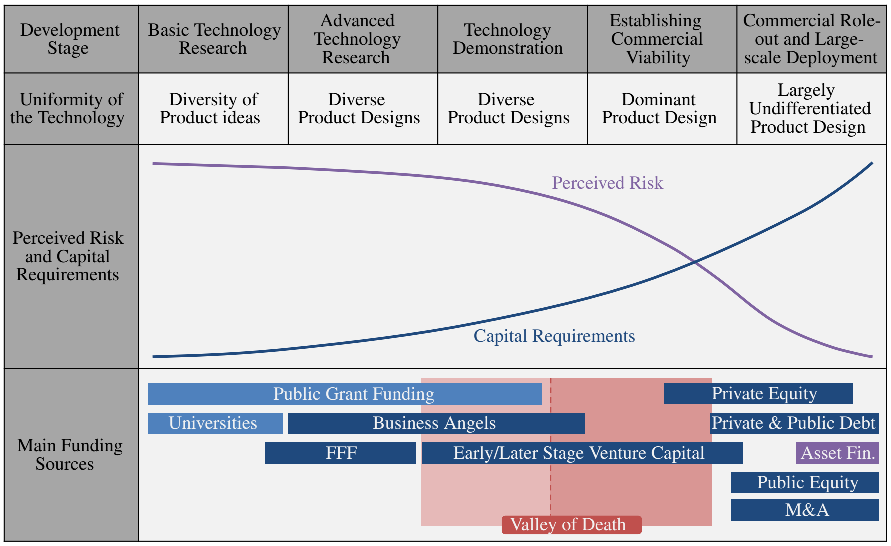

Fig. 7.1 Typical Technology Life Cycle for a Renewable Energy Technology

7.2.2 Applied Technology Research

The transition from basic to applied technology research is largely smooth without clear boundaries. The topic of applied research is typically more specific and may include the construction and testing of advanced prototypes and detailed solutions required for the later complete demonstration of the technology. Since this often occurs prior to having a final decision on all technical solutions for the product (design freeze), various alternative sub-systems are evaluated. The AWE startup Makani Power for example built and tested various soft and hard wing prototypes starting in 2006, before settling for a hard wing/on board generation combination. Generally, we would speak of applied research where the results of such research are technical solutions that can at least theoretically be patented or be kept as secret know-how and thus become valuable intellectual property (IP) of the developer. IP rights grant their owner exclusive rights to specific technical solutions and can therefore help to secure an early-mover advantage without the need to keep important information secret. They help to overcome information barriers between the innovator and investors and can be an important instrument to reduce early financing costs for innovative firms [10].

Often, funding at this stage is initially provided by the founders, their family and friends or by other informal small investors (FFF). Public funding is a second important source of finance [24]. However, the capital requirements for applied technology research often exceed the capabilities for funding from FFF and limited public support programs [15, 34]. Funding thus often draws on additional external funding sources, especially business angels, who are typically wealthy private investors and former founders of their own, but also early seed venture capital. Investment strategies of business angels are often characterized by personal attraction to the technology, entrepreneurial thrill and risk [18]. However, irrespective of personal interests business angels are rational investors who carefully select their investments and claim an adequate interest for their equity contributions. They often have a professional competence in a relevant field and provide support beyond the provisioning of funds [6, 30]. Whereas this can be appreciated support for inexperienced founders, it may also be an undesirable exertion of control and influence. Business Angels can provide substantial financing. In the US an estimated 200,000 to 400,000 business angels invest between USD 25bn and USD 50bn per year [21, 28]. The investment size of business angels typically ranges between USD 50,000 and USD 1,000,000.

7.2.3 Technology Demonstration

The technology demonstration phase usually comprises the pre-commercial testing of the technology and is characterized by considerable capital requirements for equipment as well as necessary modifications and improvements of the innovation. This is particularly true for high-tech innovations, which are typically more capital intensive than other innovations. Many AWE companies are currently in this stage; some have been for several years. They face the problem that the AWE systems are often rather complex, consist of various sub-systems (wing, ground station, control etc.) and have to cope with various modes of operation (autonomous flight, autonomous start and landing, autonomous control in extreme weather and over a long period of time etc.). While some companies have until now proven some of the functions and modes of operation, especially shorter times of autonomous flight, none has proven long-time and all weather reliability of all modes. Therefore, from an investor's perspective none of the AWE companies has to date fully left the demonstration phase. However, fully developing the various sub-systems and operation modes consumes a substantial amount of time and money while investors cannot be sure that the whole concept is working properly.

Funding requirements at this stage often exceed funding attracted from business angels or public grant funding and are typically met by venture capital investors. These provide long-term and high-risk equity particularly for small and young technology startups, which are largely constrained from other sources of funding [8, 16, 17, 20]. Against the high risk associated with an unproven technology, venture capital investment is attracted by the high profit potential inherent in investments at an early stage of the technology life cycle. For this reason venture capital particularly focuses on high-reward opportunities in perceived growth markets. The investment strategy does not assume any regular payment from the company. In contrast, payments on the investment are bound to the exit of the venture capital investor. Usually, this happens at a later stage in the technology life cycle when the startup qualifies for public equity finance (IPO) or for the sale of the startup to an established company

[7]. Target investment periods of venture capital investors typically range between 5 and 8 years [20]. A specific subtype of venture capital is corporate venture capital (CVC). CVC investors are subsidiaries of larger companies that invest in startups. In addition to an attractive return on investment, they are typically also interested in the startup as a potential future takeover target, supplier or customer. This more strategic approach to new technologies might allow longer and more costly development phases than classic venture capital can fund. Typically, CVC invests into companies of the own industry and often has the advantage of understanding the technology and the respective market better. For startups constrained from external funding, CVC can provide an attractive alternative to regular venture capital.

Beyond the financial contribution venture capital investors usually also take an active role in the development of the company. Such support includes management experience, access to the external network of the venture capital investor as well as a potential signaling effect to other investors. These factors may add a significant value to the startup [26]. However, the comprehensive controlling and voting rights that venture capital investors typically request often exceed those of angel investors and can reduce the founder's strategic flexibility [9]. On a global scale, the venture capital investment in renewable energy has amounted to around USD 3bn in 2011 [4] with typical investments by single venture capitalists of up to USD 15m [7].

7.2.4 Establishing Commercial Viability

For technologies which have demonstrated their technical viability on a smaller scale, establishing large-scale commercial viability is a critical step. Due to the lack of an institutional track record, technologies still face significant market risk at this stage and banks as well as other commercial capital providers are usually reluctant to finance this risk [15]. For this purpose, most often the only capable capital providers are venture capital investors. Investment amounts, advisory efforts as well as risk and return profiles differ to some extent from early-stage venture capital investors [26]. However, potential signaling effects from investments at this stage may increase confidence for other types of investors and may thus enable limited loan financing. Due to the difficulties of raising additional funding for capital-intensive technology innovations, the stage between technology demonstration and a full scale commercial role out is often referred to as the valley of death [15]. Typically, risks and financing difficulties are aggravated for innovations which require significant modifications between demonstrator and end product or where significantly different production methods have to be used in order to reach economically viable mass production. The variety of different sub-systems or specific products for a new technology usually decreases significantly during this development stage and a dominant design often emerges. Most AWE companies have not yet reached this development stage. However, early planning of the innovation process and the development of according financing strategies will be important to establish the commercial viability of specific AWE systems.

7.2.5 *Commercial Role-out and Large-scale Deployment*

For technologies which have survived the valley of death, most financing constraints inherent to technology innovations disappear. Typically, venture capitalists exit their investments at the transition to this stage. The demonstrated commercial viability enables the sale of former technology startups for a variety of strategic considerations to other companies such as established actors in the sector. Furthermore, access to public equity financing enables former technology startups to raise required capital for further expansion and growth via an IPO [15]. At this stage banks and public debt markets provide additional options for financing.

The funding for established renewable energy technologies such as conventional wind energy or utility-scale solar power usually disassociates from the funding of the company and is provided as asset finance [7]. For this type of funding the risk profile of the asset-producing company is no longer relevant. Instead, funding is only dependent on the cash flow and risk profile of the project itself [15]. Typically, individual projects are funded via a mix of equity investment from project owners and debt from banks. Typical project structures involve 10-40% equity and 60-90% debt. Since asset finance does not impact the balance sheet of the asset-producing company and allows to draw-in equity from a range of different equity sponsors, a large range of projects can be implemented at the same time and contribute to a fast deployment of the technology [15]. Over time, the specific design of sub-systems for the technology further converges and is largely undifferentiated for fully mature technologies. Figure 7.2 gives an overview over the range of different funding sources for renewable energy investments along the whole technology life cycle and shows their relative contribution between 2004 and 2011 with the vast majority of funds flowing into the financing of mature technology assets.

7.3 Current Challenges for Financing AWE

According to the technology life cycle framework introduced in Sect. 7.2, AWE can largely be classified in the technology demonstration phase. Typically, this development stage is characterized by a high technology risks and considerable financing needs. For the further development of the technology, AWE companies will need to establish the economic viability of technology, which requires even more funding at continued high risk. Based on the characteristics of the current development stage, this section will thus analyze the specific risks for investments into AWE and illustrate in detail the major financing challenges which AWE companies will need to overcome. The understanding and active management of the prevalent investment barriers will be important reference points for AWE companies for setting up their individual financing strategies and bridging potential financing gaps.

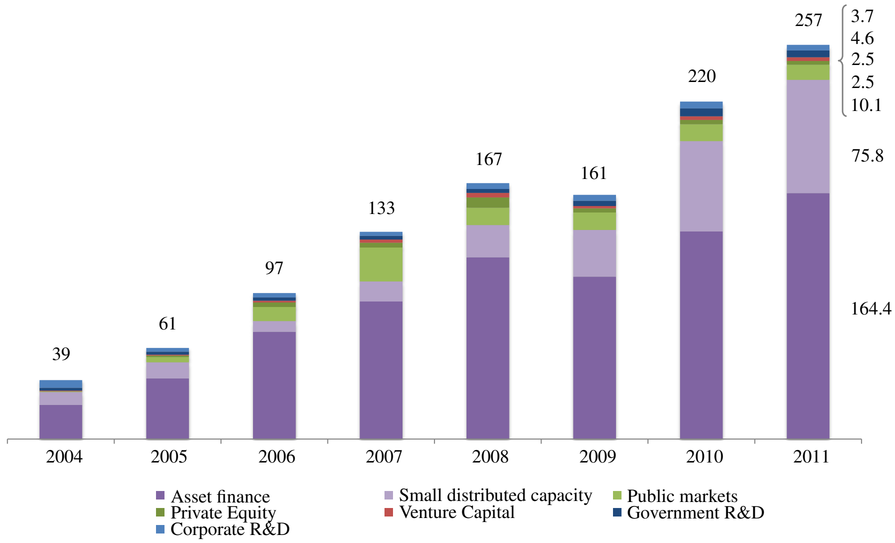

Fig. 7.2 Global New Investments into Renewable Energy (bn. US$). Source: FS-UNEP 2012

7.3.1 High Capital Intensity

A first substantial challenge for AWE in establishing commercial viability is the high overall capital requirement. Since the further development of AWE involves the development of new technologically complex and large assets and their regular modification and continuous up-scaling during the innovation process, establishing commercial viability for AWE requires significantly more capital than many other innovations do. In general, capital requirements for large technology rollouts in the renewable energy sector can easily amount to several hundred million dollars over a 5-10 year time horizon [7]. For example, the now insolvent photovoltaic solar system manufacturer Solyndra had to raise USD 970m in equity as well as a public loan guarantee of additional USD 535m prior to its IPO (ibid). For AWE in particular, the survey has revealed that expectations on required capital to develop a commercially viable utility-scale AWE device (500kW to 1 MW or larger) vary considerably between EUR 5-10m at the lower and over EUR 100m at the higher end. In any event, due to the high technology risk inherent in an investment at this stage, investors will be reluctant to provide funding in the tens of millions.

Closely linked to the high capital intensity of most renewable energy generation innovations is the length of the innovation process before establishing commercial viability [7]. Investments into renewable energy generation innovations thus carry a particularly long-lasting technology risk compared to other less capital-intensive innovations. The technology risk does not only involve the technology working on small-scale but the deployment on utility-scale (ibid). However, for high risk capital investors with a limited investment horizon, such as venture capital, long-standing technology risk may not be acceptable. Since they are guided by a portfolio strategy and invest into a broad variety of startups in order to diversify the risk inherent in each single investment, they will typically not be able to finance startups through an extended development phase. For such investors to invest it will be important to have a clear strategy to end the investment when the respective financing limits in terms of both timing and volume are reached [23]. Typically, an exit option for capital-intensive high-technology startups is the sale to another investor since an IPO is unlikely to be realized before the full commercialization of the technology.

For AWE, the length of the innovation process before commercial viability of the technology is largely unknown and needs to be assessed by an investor before a final investment decision. According to most companies in the survey, the remaining time to develop a commercially viable utility-scale AWE device may be no longer than 3-5 years. However, most founders represented in the survey lack industry experience to assess the costs and time requirements for scaling up and commercial roll out. Therefore, the assessment may be too optimistic. At the same time, Skysails, which has the longest standing experience in the AWE industry in a wider sense, has established an airborne kite towing system for ships within 10 years and raised capital of EUR 50m in total. However, while the system was up scaled to kites of up to 320 square meters, less than ten systems were sold until now.

After all, the problems created by the high capital intensity of renewable energy generation innovations may result in a considerable financing gap for startups during their pre-commercial development stage [7]. Not only for inferior technology startups, but also for promising technologies this valley of death will be difficult to overcome. It will be important for AWE companies to substantiate the case of a potentially lower capital requirement and shorter development phase. In fact, there are arguments supporting an optimistic assessment. While AWE is a new concept, many AWE designs do not require a complete new development of most subsystems. Instead, AWE could be seen as a new combination of existing technologies. Examples include the airfoil from aviation or kite sport, sensors and controls from aviation, especially military aviation where autonomous aerial drones and other unmanned aerial vehicles (UAVs) were developed with the help of massive defense budgets, as well as strong and lightweight tethers from shipping and other industries. In this case, the technology risk would be limited to the assembling of established technologies and their limited modification but would not extend to the development of completely new basic technology.

7.3.2 Lack of Established Exit Mechanisms

Besides the high capital intensity, another general financing constraint of renewable energy innovations in general is the lack of established exit mechanisms. In contrast to other financing, high risk capital including venture capital is usually clearly linked to the technology life cycle and aims to invest for a limited time only [29]. One common exit option for venture capital is via the IPO of the company. In this context, Jeng and Wells [14] have shown that the state of the IPO market may influence the supply of venture capital. However, as described above, a high capital intensity and the normally long technology life cycle for innovations in the field of renewable energy production may foreclose the exit option of an early IPO.

Another exit option, which often applies to similar capital-intensive innovations, is the sale to an established company. Ghosh and Nanda [7] claim that for companies with similar characteristics such as the biotechnology, semiconductor or IT and network industry such exit mechanisms exist and prevent companies from hitting the valley of death. However, for the energy industry a typical buyer for innovative renewable energy production firms has not emerged as far as relevant for an established exit mechanism. It will need to be seen whether a similar exit option will develop for the renewable energy sector. Wüstenhagen and Menichetti [36] state that a large range of potential investors exist for renewable technology, including large corporates, utilities and financial investors. Fritz-Morgenthal et al. [5] show that also companies within the renewable energy industry are increasingly interested in acquisitions in the same sector. Acquisitions of innovative technology startups can be triggered by perceived growth expectations for renewable energies but also by growing public support. Ghosh and Nanda [7] add that acquisitions may also happen for marketing or green washing reasons.

Although acquisitions in the renewable energy sector have so far not been sufficient to create a general exit option for risk capital investors, several acquisitions have taken place over the recent years. In the case of wind and solar energy, conventional power plant producers as Siemens, GE, ABB or Mitsubishi were slow to enter the market. However, at least some of them have at a later stage of the technology life cycle purchased solar and especially wind asset producers. Due to both their financial power as well as their know-how in the production of power plants, they could establish a strong presence in the wind industry. As to AWE in particular, from the large power plant producers only Alstom has officially invested in AWE technology but has limited its involvement to the financing of university projects. Conventional wind turbine manufacturers have so far not directly entered the field. However, due to the specific technology subsystems and specific regulation issues of AWE, the technology may also be attractive for new actors to the industry. For example, AWE startup Ampyx Power has received financing from venture capital funds whose corporate investors are from the aviation business and include KLM, a major airline and the airport of Amsterdam who are experienced with aviation technology and regulation. The technology and internet company Google is the biggest single investor in the field of AWE with their investment of over USD 15 million in Makani Power prior to the complete takeover of the company and its integration into Google in 2013.

Due to the lack of established exit mechanisms, high-risk capital investors have recently shown increased interest in less capital-intensive innovations in the renewable energy sector such as energy efficiency, energy software and storage as well as transportation, which usually feature shorter technology life cycles than energy production technologies [7]. At the same time, the focus of deals for renewable energy production has shifted to investments in component manufactures as opposed to fully-fledged energy production companies. To what extent AWE financing will be affected by the lack of an established exit mechanism will largely depend on the effective capital needs and required time to establish commercial viability (see above). At the same time, it will be decisive whether interest from established actors in the market can be attracted to demonstrate potential exit options for early capital investors.

7.3.3 Diversity of AWE Systems

A considerable diversity of technological solutions in the early stage of the technology life cycle is nothing unusual and even desirable from a macroeconomic perspective, since different specifications of the technology are tested and efficiency is likely to be increased. However, from an investor's perspective the diversity of different technological approaches represents an additional investment risk. Since one specific technology subsystem must be selected for an investment, there is the risk to choose the wrong technology sub-system even if the technology in general turns out to be successful. This risk also applies to AWE for which a considerable variety of systems are currently developed, including lighter vs. heavier than air, soft wing vs. hard wing, ground generation vs. airborne generation and yoyo vs. carousel configuration solutions. At the same time, the high capital intensity and long investment period required for AWE should aggravate the financing situation.

Despite these theoretical considerations, the AWE companies interviewed in the survey did not see a major constraint to financing related to the high diversity of technological solutions for AWE. Instead they indicated that a good argumentation of the benefits of their respective AWE solution was sufficient to convince investors of their respective technological approach. In support of this perception another interesting insight from the survey was the little engagement of not only informal investors with the AWE industry and its specifications prior to an investment. Only a minority conducts a detailed market analysis or interviews more than one AWE company in detail. This proves that the principal-agent relationship, information asymmetries and adverse selection are not only theoretical concepts but also important real life influences for the access to funding. The result is particularly surprising since better knowledge could possibly allow identifying better AWE investments in terms of risk and return. On the other hand, the information asymmetry increases capital costs for promising AWE startups as compared to competitors with worse business prospects. Without specific knowledge to evaluate the differences in the variety of subsystems, the price for capital will be based on an average calculation for the whole industry. Accordingly, unbiased additional information would be a valuable good for interested investors. For AWE companies knowing about the lack of information among investors one option to improve the access to financing would be to distribute relevant information in a more targeted manner.

In any event, the survey has shown that at least for the moment the diversity of different system solutions in the AWE industry is not such an important financing constraint as would have been expected. A reason for this observation is offered by the fact that the majority of experts does not expect that only one AWE system will survive. At least over the medium term different systems could be applied in different circumstances (for example on-grid and off-grid, onshore and off-shore solutions). In general, both a high convergence as well as a residual diversity of systems could be observed in the long run. For example in the conventional wind industry, a dominant technical design (horizontal axis, three-bladed upwind turbine) has evolved and squeezed out a multitude of other designs, which have been developed in the early stages of the technology life cycle (vertical axis, two-bladed turbines, downwind turbines etc.). In contrast, the car industry is a good example of a mature industry in which two versions of a main design feature, the engine, have survived for more than hundred years. Both petrol and diesel engines have co-existed even though keeping up the two systems has doubled not only the costs for the technology development but also additional expenditures such as maintaining the required infrastructure for the mature technology.

7.3.4 Renewable Energy as a Commodity

An important distinction between technology startups in the renewable energy sector and other high-tech startups are the characteristics of energy as a commodity in comparison to products from other innovation processes such as the development of new software. If environmental costs of the production of most conventional energy sources including CO_2 emissions are not internalized in the cost of energy, innovations for the production of renewable energy do not produce a differentiated new product [7]. To end-users it usually does not matter whether their energy demand is served by an innovative renewable energy technology or any other energy source. However, for investors in startups for renewable energy technologies the low degree of differentiation of the end product represents a considerable market risk and may significantly influence the investment decision. The value of the investment is no longer only dependent on technology risk but also to a considerable extent on external market conditions for the energy sector including volatile energy prices and regulation. At the same time, both investor and startup have no direct influence on the development of the market conditions. Although also innovations in other sectors such as the IT industry face some market risk, the little value added by new energy production technologies in terms of product quality increases the risk exposure substantially. In contrast to technology innovations in the energy sector, most other radical technology innovations create a market for themselves and are thus less dependent on the economics of an established market. The price, which can be achieved for a new pharmaceutical, for example is largely determined by its additional utility to the market. In contrast, the price to be achieved for electricity from a new renewable energy technology does not offer an additional utility and will thus equal the price of electricity from any other generation source if there is no subsidy scheme in place.

Although AWE does not make an exception in terms of the commodity produced, the market risk may be lower as compared to other renewable energy sources. Most AWE companies in the survey expect that the cost of electricity produced from AWE will be competitive with established energy sources such as coal even for early-stage production devices. Therefore, the market potential and interest in AWE is likely to remain high even for unexpected developments in the energy market. However, it must be considered that even under the most optimistic scenarios it will need another 3-5 years before utility scale AWE devices become available. During this time the prices for established renewable energy sources such as solar or conventional wind may further decrease and diminish the advantage of AWE in terms of competitiveness and market potential.

Other disruptive changes in conventional fuels, such as the shale gas and tight oil developments in the US, which led to substantially lowered cost of energy, also have the potential to jeopardize the expected economics of AWE. However, the increasing impact of a largely fossil fuel-based energy system on the global climate system reduces the market risk for renewable energy. Ever more governments have introduced policy mechanisms to internalize negative environmental impacts from traditional energy production or to support the share of energy from renewable sources (e.g. via carbon taxation, feed-in-tariffs, tax subsidies, CO_2 allowances, quotas, etc.). Renewable energy can therefore be seen as a somewhat more valuable commodity, which can and does in many cases attract higher prices than electricity generated with fossil fuels.

Another important attribute of renewable energy as a commodity relates to its geographic distribution, which differs considerably between different countries and regions [15]. In contrast to fossil energy sources, renewable energy is fundamentally non-tradable. Renewable energy production facilities thus need to be built in regions with attractive conditions regarding wind or solar exposure. Therefore, market potential is partly dependent on whether the renewable resource is available at places with high electricity demand, which may influence an investor's valuation for a technology startup already early in the technology life cycle. However, since AWE makes use of high altitude winds, which are more constant and more widely available than other renewable energy sources, the technology may be less exposed to this issue. In fact, the large application potential of AWE significantly increases its market potential as compared not only to other renewable but also conventional energy sources.

7.3.5 Exposure to Policy Risk and Subsidies

Even if grid parity has been reached at some places, renewable energy sources have not fully reached commercial viability, and moreover substantially depend on external environmental influences. Further maturation of the industry will be required, including both radical and incremental innovations for established technology subsystems. However, due to public interest more than 80 countries have implemented public support instruments in order to ensure commercial viability for private investors and to foster the further deployment of renewable energy at scale and their cost degression [27].

Moore and Wüstenhagen [20] have shown that government support for renewable energies has a critical role also at an early stage in the technology life cycle. Besides direct support for innovations, public support indirectly influences the market for risk capital due to effects on the economics of energy investments at a later stage. As described in the previous section, subsidies can reduce market risks for private investors and critically influence the commercial viability and attractiveness of investments in the technology. However, against the background that most renewable energy sources are not yet commercially viable without additional public subsidy, government support does not only represent an instrument for risk mitigation but also creates considerable political risk for private investors in itself if unexpected policy changes impact the profitability of their investment [19]. In this context, Usher [35] mentions that investments in renewable energy assets and respective sales of renewable asset manufacturers are strongly influenced by the level of risk that renewable asset investors face under the respective policy instrument.

For AWE the exposure to policy risk concerning subsidies may be significantly lower than for other renewable energy technologies. Assuming that AWE will be competitive in terms of energy production costs already at an early development stage, it will not need to rely on additional public subsidies. Nonetheless, our survey among AWE companies has shown that despite the little expected dependence on public support for the competitiveness of AWE, interest in the technology is indirectly influenced by policy changes in the renewable energy sector. According to the AWE company Makani Power, the expected expiration of the tax credits for wind energy in the US at the end of 2012 led to a significant drop in investor interest in the second half of 2012. Investor interest only increased again in January 2013 after a generous prolongation of the tax credits had been enacted. Ghosh and Nanda [7] argue that particularly high-risk investors such as venture capital funds may have little experience with policy risks, which result in failure to analyze given investment opportunities in an appropriate way.

7.3.6 Other Perceived AWE-specific Risks

Besides the above-described risks, AWE also faces innate risks, which are linked to the technology itself and cannot be classified in a more general category. AWE has not yet proven commercial viability and still faces considerable technology risk – according to our survey especially with regard to autonomous start and landing, the general robustness of the systems over a longer time and with respect to the maintenance and scaling up of systems. Nonetheless, most survey participants show a considerable confidence that any remaining technological questions can and will be solved. At the same time expectations are that obtaining financing will become much easier once a full-fledged technology demonstrator exists and works reliably over a longer time. This indicates that despite general confidence investors perceive residual technology risk, which does constrain the access to finance. However, compared to other high-technology innovations, the technology risk of AWE seems to be manageable.

Besides technology risk another important risk for AWE are required permits and certification of the technology. Although the risk also applies to other innovations, it is particularly relevant for AWE, which creates a potential hazard as airborne device and may need to use regulated airspace. AWE will only be able to be deployed on a larger scale and capitalize on its theoretical potential if operating permits and certification for AWE devices can be obtained. However, no regulation exists yet. Even the type of operating permit to be obtained is not clear, especially whether AWE devices will be treated as aerial vehicles, which have to comply with very strict and costly safety standards, or as aerial obstacles. This issue could likely become an important driver of costs and time delays for AWE companies. At the same time, the requirements and the amount of time for completion of certification and obtaining permits in the various jurisdictions is difficult to foresee, especially since no AWE company so far has obtained a permanent operating permit or certification. Most interviewees considered these more political risks and uncertainties to be much more important than other specific technology risks.

The risk could be mitigated by choosing countries or regions which have established a favorable regulatory regime for the first deployment of AWE devices. The costs and risks of establishing regulation and certification standards could also be lowered for each AWE company if several companies joined their efforts and cooperated in this field. Worldwide deployment should become easier once a longer successful operating history has been proven. On the other side, a fatal incident of one AWE device could tempt regulators worldwide to raise the regulatory hurdles for all AWE devices substantially.

7.3.7 Behavioral Influences

Besides a rational assessment of risks, additional constraints to financing for innovative renewable energy startups can be explained by the influence of behavioral aspects. Already in the 1950s it has been shown that human decisions are not fully rational but strongly influenced by a variety of cognitive factors [31]. For financing decisions under uncertainty a series of cognitive biases strongly influences decision-making with the result of a potentially inappropriate assessment of the probability of events [33].

Both investment decisions for the financing of innovations on the one hand and for the financing of renewable energies on the other hand do involve a high level of uncertainty and risk and are thus susceptible to behavioral influences. Although this applies to any of the above-described risks, some are particularly prone to cognitive biases. A particularly important aspect is the limited in-depth knowledge many investors have of AWE. Despite the specific characteristics of the technology, including its high competitiveness and lower reliance on subsidies, most investors do not sufficiently distinguish AWE from other renewable energy technologies. For this reason, the assessment of investments into AWE is largely driven by the perception of the current deep crisis among renewable energy companies which led to a large number of insolvencies among wind and solar manufacturers worldwide. The state of the renewable energy market as well as a general risk aversion of potential investors after the financial crisis have accordingly been mentioned in the survey as important reasons for constrained financing of AWE companies. This risk aversion coupled with poor returns of venture capital funds in the wake of the dotcom and venture capital boom of the millennium have led to fundraising difficulties of the venture capital industry as well as to concentration on perceived lower risk investments by venture capital funds. Currently, many venture capital funds stay clear of seed and early stage investments in capital intensive industries and focus on investments that require less technology and market development and promise relatively quick and safe returns [3]. Understanding behavioral influences will be important to identify opportunities to improve the access to funding by AWE companies.

7.4 Conclusion

Availability of financing is always dependent on an attractive perceived risk-return profile for the investor. Section 7.3 has established that many AWE companies are currently in the technology demonstration phase of the technology life cycle, which is determined by high risks and increasing financing needs. For the further development of the technology, AWE companies will have to establish economic viability, which requires even further increased financing at continued high risk. In this context, Sect. 7.4 discussed the specific risks for investments in AWE companies. These will need to be managed if substantial additional risk capital is to be raised. While good arguments exist for a viability of the technology, it has to be concluded that AWE financing involves considerable challenges and will remain risky also for the next stages of the technology development. Financing is and will therefore remain to some degree constrained.

7.4.1 Current Financing Strategies of AWE Companies

In order to gain information on how AWE companies cope with the constraints to financing, which are characterizing their current development stage, the major players in the industry were asked for information on their current structure and sources of financing. The survey revealed that AWE companies in fact use very different funding sources and basically no general trend exists other than that almost all interviewed companies obtained some type of public funding.

Generally, the availability of public funding reduces the risk for private investors by leveraging the investment with public funds, in most cases without the requirement to share the upside potential. The availability of a certain percentage of private financing is often a prerequisite for such subsidies and serves as a test for the viability of the project. According to our survey public funds have in many cases contributed between 25% and 75% of total R&D costs of AWE companies. However, while the availability of public funding was critical for the financing of a number of AWE companies, it often also involves high compliance costs like additional bookkeeping and disclosure requirements, which may jeopardize the company's IP, as well as strict project specifications, which can result in a non-optimal design [26].

For public financing parties it is often very difficult to assess the viability and merit of technology developments. Public support might therefore in many cases not be provided to the most promising technologies. Specific public AWE financing programs do not exist. However, the ARPA-E program in the USA was specifically set up to provide financing to solutions in renewable energy and financed the AWE company Makani Power. In Germany the research institution Fraunhofer IWES was asked by the responsible federal ministry to conduct a technology assessment of AWE as a preparation for a decision on potential subsidies in this field.

Besides public subsidies, the survey has revealed an important role for a large variety of private funding sources. FFF, business angels and other high net-worth individuals, venture capital funds and corporate investors have all provided funding so far. Some companies were funded primarily by one investor or one type of investor. Others approached a multitude of investors from different classes. As to our information most venture capital funds that have invested so far had a corporate background or their investors were mainly companies and could therefore be classified as CVC in the broader sense. Besides the Google investment in Makani Power, Skysails is particularly interesting in this respect, since its corporate investors DSM (Dyneema® fibre) and Zeppelin (ship propulsion and servicing) have an interest in the technology development as potential supplier or provider of services. In this context, it can be noted that so far no major company from the wind energy or general energy sector has invested into AWE companies with the exception of the Norwegian electricity supplier Statkraft's investment in Ampyx Power. However, several professionals from the wind energy business or general energy industry have privately invested in AWE companies.

Some of the AWE companies in the survey have received a large share of funding from small individual investors, pooled in investment vehicles. For small investors such investments may be considered as a way of supporting a good cause, which can increase their willingness to accept the high level of risks involved. Some companies contemplate to follow this funding model and offer crowd funding, which Ampyx Power has already done successfully. This new internet-based way of funding allows small private investors, with minimum investment sizes of sometimes only a few hundred USD, to directly invest in innovations. However, it has to be mentioned that such small investors have neither the possibility nor the economic incentive to conduct a full risk assessment of AWE and will rather base the investment decision on their gut feeling.

By and large, the survey has shown that against the substantial risks involved in investments into AWE companies the industry has so far managed considerably well to attract financing. Innovative funding approaches have been a large part of this story. However, securing sufficient funding will remain a constant issue for AWE companies and also requires dedicated efforts beyond work on the technological development.

7.4.2 Outlook for AWE financing

Despite creditable success in managing the existing financing constraints for AWE so far, additional funding will be critical to establish commercial viability for AWE. Against the size of funds required at this development stage, the funding sources so far employed will most likely be no longer sufficient and (institutional) risk capital, partly already involved today, will have to play a more and more prominent role.

One option could foresee strategic alliances with other stakeholders. Collaborating with wind developers or utilities in the financing of the first test parks on the basis of joint ventures could be a promising opportunity. Depending on the terms of such financing and the returns of the first test devices, a co-financed park could also generate first returns for the AWE companies and become a relevant source of additional (internal) financing. Lowering the perceived risks in investments into AWE wind parks will at a later stage be most important in order to bring down return requirements of wind park investors and allow higher sales prices for the AWE devices. However, it will take years of proven reliability before banks will finance AWE parks with the favorable conditions that conventional wind or solar assets enjoy today. Where possible, collaboration may also be promising within the AWE industry. Where different AWE companies have acquired know-how on complementary subsystems, such as on the aerial vehicle, ground station, controls, regulatory requirements and regimes etc. collaboration may reduce both specific risks as well as the capital requirements for an individual company and may therefore increase the access to funding.

Strategic cooperation should also involve a more targeted search for investors. Looking for less institutionalized venture capital such as corporate venture capital could for example increase the investment horizon of external capital, which might be necessary before commercial viability can be established. At the same time, strategic investors can provide an interesting exit opportunity for traditional venture capital, which may otherwise be reluctant to invest over an incalculable term. Possibly, raising interest for the technology or a specific AWE system among other potential buyers at a later development stage may also have spillover effects to investors with a limited investment horizon.

In any event, it will be important to understand cognitive biases and behavioral influences of investors in order to anticipate them where possible in setting up sound financing strategies. In some events, the provision of particular information may significantly reduce perceived risks of investors, which so far have very limited knowledge of AWE. Setting up more effective information channels and improving the work in industry associations could be options to do so.

But not only AWE companies, also relevant high risk capital investors in the field can draw lessons from the findings of the article. If better information about the sector or adjustments of their investment strategies, such as allowing longer holding periods until exit, may positively influence the risk-return structure of investment opportunities, venture capital funds should consider applying these approaches. Cooperation or pooling among investors in AWE could lower both, the costs incurred by gathering in depth information on the technology and the risk of insufficient funding over the long time period until exit.

Overall, the article has illustrated a broad range of starting points for both AWE companies as well as investors to set up financing and investment strategies in order to overcome capital market imperfections, which are currently and will continue to constrain financing in the next stages of the development. A substantial change in the perceived risk profile of AWE companies will probably occur once the first full-fledged technology demonstrators are available and have proven reliability over a longer time period. Positive news regarding one specific AWE company will affect the industry as a whole and technological successes of one company will have a positive effect on the financing conditions of competitors as well. Once reliability and economic viability have been proven at scale, AWE will be able to unfold its full market potential: An estimated 10 trillion USD will be globally invested in new electricity production plants until 2035, more than 60% of which in renewable energy assets [13]. For a technology which can capture even only a small share of this market, financing will no longer be a major concern.

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