energies
MDPI

Review

Wind Turbines from the Swedish Wind Energy Program and the Subsequent Commercialization Attempts—A Historical Review

Erik Möllerström

The Rydberg Laboratory for Applied Sciences, Halmstad University, PO Box 823, SE-301 18 Halmstad, Sweden; erik.mollerstrom@hh.se; Tel./Fax: +46-35-16-7971

Received: 23 January 2019; Accepted: 16 February 2019; Published: 20 February 2019

check for updates

Abstract: This paper summarizes wind turbines of Swedish origin, 50 kW and above. Both the large governmental-funded prototypes from the early 1980s and following attempts to build commercial turbines are covered. After the 1973 oil crisis, a development program for wind turbine technology was initiated in Sweden, culminating in the early 1980s with the 2 and 3-MW machines at Maglarp and Näsudden. However, government interest declined, and Sweden soon lost its position as one of the leading countries regarding wind turbine development. Nevertheless, several attempts to build commercial wind turbines in Sweden were made in the following decades. Most attempts have, like the earlier prototypes, used a two-bladed rotor, which has become synonymous with the Swedish wind turbine development line. The current ongoing Swedish endeavors primarily focus on the niche-concept of vertical axis wind turbines (VAWTs), which is a demonstration of how far from the broad commercial market of Sweden has moved. Thus far, none of the Swedish attempts have been commercially successful, and unlike countries like Denmark or Germany, Sweden currently has no large wind turbine producer. Suggested reasons include early government interventions focusing on two-bladed prototypes and political disinterest, with wind power grants cut in half by 1985, and the domestic industry not being favored in government policies for deploying wind power.

Keywords: wind power; Swedish wind energy research program; wind power history

1. Introduction

Denmark was an early frontrunner in wind power, with Poul LaCour constructing one of the first electricity generating wind turbines in 1891 (Scotsman James Blyth constructing the first in 1887), and the 200-kW Gedser turbine installed in 1956 [1,2]. There was also early activity in other countries, for example, the American 1.25-MW Smith-Putnam turbine was erected as early as 1941 [1,2]. Sweden could also have had an early start. In a governmental investigation in 1956 of the future energy supply of Sweden, the potential of wind power was acknowledged, and a 1.2-MW test wind turbine was proposed. This was never realized and it would be nearly another 20 years before wind power became of interest in Sweden again [3]. After the 1973 oil crisis, there have been notable attempts in every decade to develop medium-to-large commercial wind turbines in Sweden. However, unlike countries like Denmark, Germany, and Spain, Sweden currently has no successful wind turbine manufacturer.

1.1. Aim of the Paper

The Swedish attempts to develop commercial wind turbines are to various degrees well known and easily accessible. Finding and accessing information about the history of these projects is important to understand the Swedish part in the evolution of wind power, and why Sweden currently has no commercially successful wind turbine manufacturer. There is work covering various aspects of the

Swedish wind turbine industry. Without going in depth on the Swedish case, a historical description of global wind turbine development can be found in [1,2,4]. In [5], an assessment of the effects and cost efficiency of the Swedish wind energy program between 1975 and 2000 can be found, and in [6,7], the Swedish wind turbine industry is compared to those of Germany and Holland with the aim of explaining their relative success and failure. There are a few books written in Swedish that cover the history of Swedish wind power. For example, the historical attempts to build wind turbines in Sweden and wind energy as a whole in Sweden can be found in [8]. In addition, in Swedish, the history of wind power in Sweden between 1973 and 1990 focusing on energy politics and industrial development can be found in [9]. However, there are no easily accessible English-language paper-format summaries covering the Swedish attempts to build commercial wind turbines. A focus on wind turbines and manufacturers rather than political frameworks, highlighting the most relevant literature for the different projects, will be the main purpose of this paper. In addition, the possible reasons given in several studies for Sweden not having any wind turbine industry will be summarized.

1.2. Limitations

This paper focuses on the attempts to develop medium-to-large wind turbines in Sweden. To focus on the attempts closest to establishing themselves in the market, only projects in which an actual turbine of at least 50 kW was built will be covered (although some other activity is mentioned in Section 4. "Other Notable Swedish Contributions to Wind Turbine Development"). The history of wind power being established as a significant part of the Swedish electricity mix is also left out.

2. Governmental-funded Prototypes

During the oil crisis of 1973, there was a renewed global interest in wind power, which was further enhanced in Sweden due to an initial opposition to nuclear power [8,9]. Several government-initiated work groups and investigations were started, and in 1975, a wind energy research program, a national program for developing wind power, was started and put under a new administrative authority with responsibility for national energy research programs: The National Swedish Board for Energy Source Development (NE; in Swedish: Nämnden för energiproduktionsforskning) [5]. The program soon concluded that, with the lack of commercial large-scale turbines on the international market, a number of wind turbines in various sizes should be constructed and tested in Sweden [8]. After erecting a 60-kW turbine (see Section 2.1 "Kalkugnen 60 kW"), it was suggested by NE in 1977 that one to three large wind turbine prototypes from different producers should be constructed [10]. The Swedish government greenlighted two prototypes that were to be built with a requirement specification of turbines 70 to 90 m in diameter, a tower height equal or above the diameter, 2 to 4 MW of rated power, and 2 to 3 turbine blades [11]. In total, five bids were made, resulting in the turbines at Maglarp and Näsudden (see Section 2.2 "Maglarp WTS-3" and Section 2.3 "Näsudden I (WTS-75)") [12].

2.1. Kalkugnen 60 kW

In 1977, an experimental 60-kW turbine was constructed and erected in Älvkarleby, Uppsala County by an initiative from NE in collaboration with Saab-Scania AB [13–15]. This 18-m downwind turbine, which can be seen in Figure 1, had two pitch-regulated aluminum blades bolted rigidly to the hub, which was connected to an asynchronous generator by a gearbox. After a year, the rigid hub was replaced with a flapping hub, which is an assembly where each blade is hinged to the hub and thus can move some degrees out of the turbine plane to reduce loads. The aluminum blades were later replaced by fiberglass-reinforced plastic blades. The turbine operated as expected until 1980. The blades where then to be replaced again to test carbon-fiber-armed plastic blades, when the nacelle crashed to the ground in a mobile crane incident, destroying it completely. Notably, wind data from the Kalkugnen wind turbine was used to test early wind turbine wake models [16,17].

Figure 1. The Kalkugnen and Maglarp turbines. Left: The 60-kW Kalkugnen turbine at Älvkarleby. Photo used with permission from SAAB. Center and right: The 3-MW WTS-3 turbine at Maglarp. Photo used with permission from Jos Beurskens (center, all rights reserved) and Sydkraft/E.ON (right).

2.2. Maglarp WTS-3

The shipyard Karlskronavarvet became one of the bid winners with their two-bladed, downwind design with a teetering hub. The 3-MW turbine, which can be seen in Figure 1, had a rotor diameter of 78 m and an 80-m tower. Unconventionally at the time for such a large turbine, it used a soft tower, which can be made considerably thinner than a stiff tower and has become the standard for multi-MW turbines. The design was developed in cooperation with the U.S. based Hamilton Standard, which in 1982, erected a 4-MW version of the turbine (a.k.a. WTS-4) at Medicine Bow, Wyoming [18–20].

The Swedish WTS-3 was erected in 1983 at Maglarp in Skåne County, which is close to the southern peak of Sweden. A number of minor modifications had to be done during the first years of operation, but overall the turbine worked quite reliably, although the fixed speed in combination with the high specific power gave a high cut-in wind speed (7 m/s), thus the turbine was often standing still, giving the impression of a malfunction [8]. The turbine was taken out of operation and demolished in 1993. It had generated 37 GWh during its 11 years of operation, at the time, a world record for wind turbines [21,22].

2.3. Näsudden I (WTS-75)

The other bid winner was Karlstads mekaniska werkstad (KMW), which proposed a 75 m, two-bladed, upwind turbine with a beveled gear that enabled placing the asynchronous generator inside the tower rather than in the nacelle [14,23,24]. Like most other multi-MW wind turbines at this time, this turbine had a stiff tower. To achieve this, the concrete tower had to be made considerably thicker than a conventional soft tower, where the first-mode eigenfrequency is quickly excited during speed-up. The turbine was located at Näsudden, Gotland and started operation in 1984. As for the Maglarp turbine, many components had to be repaired or modified within the first years of operation [21]. The stiff set-up without damping was problematic, possibly contributing to the cracks that appeared in the steel beams of the blades. The cracks in the blades were repaired by welding but ultimately, in 1988 the operation of the turbine had to be halted after a crack appeared close to the hub in one of the blades. The turbine and nacelle were dismantled in 1991, but the concrete tower was left and later reused for Näsudden II [25]. Näsudden I was used for several different field studies, for example, in [26], the wind wake behind the turbine was measured with a sodar.

2.4. Näsudden II

Using the findings from Näsudden I and Maglarp turbines, a new large wind turbine was designed in a joint German-Swedish collaboration led by KMW and later by its successor, Kvaerner Turbin. The turbine, which was officially named Näsudden II but was more commonly referred to as Matilda, can be seen Figure 2. This 3-MW turbine used the stiff tower from Näsudden I, but unlike its predecessor, the 80-m blades were made out of glass and carbon fiber instead of the problematic steel-beam design [27]. Näsudden II was commissioned in 1993 and by the time it was put out of operation after a gearbox failure in 2006, it held the world record for electricity generation for a wind turbine with 61.4 GWh [22,28]. In addition, erected in 1993, Näsudden II had a sister turbine, Aeolus II, near Wilhelmshaven in Germany [27]. The two turbines were identical with the exception that Aeolus II had a soft concrete tower and variable speed (Näsudden II was a dual-speed machine).

Figure 2. The Näsudden turbines. Left and center: The 2-MW Näsudden I (WTS-75) at Näsudden, Gotland. Photo used with permission from Vattenfall (left) and Jos Beurskens (center, all rights reserved). Note the lift platform that was used for erecting the nacelle, and thereafter the blades, during assembly. Right: The 3-MW Näsudden II at Näsudden, Gotland. Photo by and used with permission from Gunnar Britse.

3. Attempts to Commercialize

The first phase of the Swedish wind energy research program ended in 1985. During the latter half of the 1980s, the focus of wind power development in Sweden shifted toward wind turbines from foreign manufacturers [8]. With the introduction of investment subsidies for wind power in 1991, the number of actors increased, and predominantly Danish and German wind turbines were installed in the growing wind power market in Sweden [5]. Although no longer possible to obtain fully covered government funding for commercial attempts to develop wind turbines in Sweden, partial funding was still offered [5]. These funds were administrated by the National Energy Administration (STEV; in Swedish: Statens energiverk), which replaced NE in 1983, and later by NUTEK (Swedish National Board for Industrial and Technical Development; in Swedish: Verket för näringslivsutveckling), which in turn replaced STEV in 1991. There have been several Swedish attempts to develop commercial wind turbines from the 1980s until the 2010s and below are descriptions of the projects that have resulted in 50 kW or larger wind turbines (see Table 1 for details).

3.1. Zephyr Energy

The company Zephyr Energi AB was started in 1988 in Falkenberg by Leif Svensson [29]. With a concept from Sven Svenning, a former engineer from SAAB's airplane division, Zephyr used a passive pitch system, where the outboard section of the blades was pitched by the aerodynamic torque acting along the blade axis when the rated wind speed was exceeded [30,31]. With financial support from STEV/NUTEK, a 250-kW, 28-m flapping hub model was developed (see Figure 3). In total, seven turbines were produced between 1989 and 1997 [32,33]. Zephyr also designed an upscaled 750-kW version of the turbine, which was never built due to the lack of success with the 250-kW model [34]. The erected 250-kW turbines were troubled; apparently, the scaling effect had not been accounted for during design. The steel-core blades with the added mass from the passive pitch solution had been tested with relative success on smaller turbines, but simply became too heavy for the larger turbines, resulting in destroyed bearings in the flapping hub. Ultimately, Ultimately, Zephyr Energy ceased its activities in 1998. Zephyr's concept for passive pitch was used for a number of years by Pitchwind Systems AB, which sold a 20–30 kW two-bladed turbine [35].

Figure 3. Zephyr and Nordic Windpower. Left: A Zephyr 250 kW near Falkenberg with the outboard section of the blade pitched. Photo used with permission from Falkenberg Energi AB. Right: A parked 1-MW Nordic 1000 near Halmstad, Halland County (2019). Photo by Erik Möllerström.

3.2. Nordic Windpower

Through the initiative of the consulting firm ÅF Industriteknik and Hägglund components, the company Nordic Windpower started in 1990. Nordic's turbine design was partly based on the Maglarp concept with a soft tower and two blades on a teetering hub, but unlike the Maglarp turbine, it had stall regulation and an upwind rotor. In 1992, a 400-kW prototype was erected near Lysekil [32,36,37]. Nordic aimed to make lightweight turbines, and this first design reportedly had a 40% lower mass than the Danish wind turbines of equal size at the time [32,36]. Nordic then developed an upscaled 1-MW design (see Figure 3) with funding from the EU. A total of four were built between 1995 and 2003 [36,38–41]. Nordic Windpower was sold to three investors in 1999, and ultimately, the staff took over the company in 2002. After problems finding new investors and customers, Nordic Windpower went bankrupt in 2005 [42]. As of late 2018, two out of the four Swedish Nordic 1000 turbines were still operating.

Several former Nordic employees started Deltawind, which bought the assets of Nordic Windpower [8]. In cooperation with Chinese Wuhan Guoce Science Technology, Deltawind erected 120 Nordic 1000s in northern China between 2008 and 2012. After this, Deltawind was bought by an American consortium in 2007 and Nordic Windpower USA inc. produced six more Nordic 1000s before the company went bankrupt in 2012 [43].

3.3. ScanWind

After Kvaerner discontinued its wind energy division in the late 1990s, some of its staff initiated ScanWind. The company, which was owned by the Norwegian power utility NTE (Nord-Tröndelag Elektrisitetsverk), was established in 1999 with the headquarters in Trondheim, Norway, but with the main design office in Karlstad, Sweden. Influenced by the Näsudden II design, ScanWind developed a three-blade, direct-drive concept, and their first 90-m, 3-MW turbine was commissioned in 2003 at Hundhammerfjellet, Norway (see Figure 4). In total, 15 turbines were erected at the site, of which 11 were of the uprated 3.5-MW version (ScanWind also tested a gearbox version at the same site) [44]. The turbines experienced problems with yaw bearings, and there wee three cases of blade failures [45,46]. Since 2009, the 15 ScanWind turbines at the Hundhammerfjellet Wind Farm has gradually been taken out of service, and as of January 2019, the last seven turbines are awaiting dismantling. ScanWind was sold in 2008 to the Swedish company Morphic, which sold it in 2009 to General Electric (GE). GE declared its intent to base its new line of off-shore wind turbines on ScanWind technology, and in 2011, a 4.1-MW demo turbine was erected in Gothenburg [47]. However, the development line was discontinued soon after, and the offices in Trondheim and Karlstad were closed.

Figure 4. ScanWind and Vertical Wind. Left: ScanWind 3.5-MW turbines at Hundhammerfjellet, Norway. Photo by and used with permission from Anders Wickström. Right: The 200-kW Vertical Wind H-rotor in Falkenberg. Photo by Erik Möllerström.

3.4. Vertical Wind

Researchers at Uppsala University developed a direct-drive, variable-speed, multi-pole, synchronous permanent magnet (PM) generator, which they used on several small three-bladed experimental vertical axis wind turbines (VAWTs) [48,49]. The concept was upscaled by Vertical Wind AB, a spinoff from the university's VAWT research, which started in 2002, and installed a 200-kW prototype near Falkenberg in 2010 that is still operational (see Figure 4). As there were problems with the attachment of the wooden tower to the foundation, guy cables were added after two years [50]. After operating at limited wind speeds for nearly a full year from 2011 to 2012, the turbine was used sporadically for experimentation for several years [51–53]. After a minor overhaul in 2018, it once again commenced automatic operation.

Table 1. Built Swedish wind turbines/prototypes of at least 100 kW.

Name	Producer/affiliations	No	Location	Year	Dimensions	Power	Description	Status	Ref
Kalkugnen	Saab-Scania, Vattenfall, NE.	1	Älvkarleby, Uppsala County	1977	D: 18 m. H_{hub}: 25 m.	60 kW (75 kW max) @ 10 m/s	Two-bladed. Downwind. Asynchronous generator. Gearbox. Full pitch. Aluminum blades (later glass fiber-reinforced plastic blades).	Destroyed in crane incident in 1980.	[13–15,54]
WTS-3 Maglarp	Karlskronavarvet (Svenska varv: Swedyards) Hamilton Standard, Sydkraft, NE.	1	Maglarp, Skåne County	1983	D: 78 m. H_{hub}: 80 m.	3 MW @ 14 m/s	Two-bladed. Downwind. Synchronous generator. Gearbox. Full pitch. Fiberglass blades. Steel tower. Fixed-speed (25 rpm). Teetering hub.	Operation ended and demolished in 1993.	[13,20,21, 55]
Näsudden I WTS-75 (a.k.a. Albertina)	KMW (KAMEWA), Vattenfall, NE.	1	Näsudden, Gotland	1983–84	D: 75 m. H_{hub}: 77 m.	2 MW @ 12.5 m/s	Two-bladed. Upwind. Asynchronous generator. Gearbox. Full pitch. Fixed speed (25 rpm). Steel-core blades with fiberglass-reinforced plastic. Concrete tower. Stiff tower set up.	Operation ended in 1988 and demolished in 1991. Tower reused for Näsudden II.	[13,14,21, 23,24,56]
Näsudden II (a.k.a. Matilda)	Kvaerner turbine(formerly KMW)Vattenfall		Näsudden, Gotland	1993	D: 80 m. H_{hub}: 78 m.	3 MW @ 14 m/s.	Two-bladed. Upwind. Asynchronous generator. Gearbox. Glass fiber/carbon blades. Full pitch. Dual speed (21/14 rpm). Concrete tower. Stiff tower set up.	Operation ended in 2006. Demolished in 2008.	[22,27,28]
Zephyr WTS 28.250 (WTS 26.250)	Zephyr Energy, NUTEK.	7	Various locations in Halland County	1989–97	D: 28 m. H_{HUB}: 33 m (first turbine: D: 26 m. H_{HUB}: 32 m).	250 kW @ 11 m/s.	Two-bladed. Jointed blades for passive pitch. Asynchronous generator. Gearbox. Dual-speed. Steel tower. Steel-core blades covered in glass fiber-reinforced plastics.	All out of operation by ca 1999.	[31,32]
Nordic 400	Nordic Windpower	1	Lyse, Lysekil. Västra Götaland County	1992	D: 35 m. H_{HUB}: 40 m	400 kW @ 13 m/s	Two-bladed. Asynchronous generator. Gearbox. Variable speed. Teetering hub. Stall regulated. Steel tower.	Out of operation in 2001. Dismantled in 2002.	[36,57,58]
Nordic 1000		4 (+126)	Näsudden, Gotland. Halmstad, Halland	1995–2003	D: 53 m. H_{HUB}: 58 m (Low-wind version: D: 59 m. H_{HUB}: 70 m)	1 MW @ 16 m/s		Two still in operation 2018 (Näsudden and Halmstad).	
3000 DL 3000 GL 3500 DL	ScanWind	3 1 11	Hundhammerfjellet, Nærøy, Norway	2003–05 2004 2006–07	D: 91 m (first 3000 DL: 81 m). H_{HUB}: 74 m.	3 MW @ 14 m/s 3 MW @ 14 m/s 3.5 MW @ 16 m/s	Three-bladed. Direct driven PM generator (Asynchronous generator and gearbox for GL model).	Gradually taken out of service since 2009. Last seven turbines to be dismantled in 2019.	[44]
T1-turbine	Vertical Wind, Uppsala University.	1	Falkenberg, Halland	2010	D: 26 m. H_{HUB}: 40 m. L_{BLADE}: 24 m.	200 kW @ 12 m/s	VAWT H-rotor. Two-bladed. Direct-driven PM generator. Variable speed. Drivetrain on ground. Fiberglass blades. Tower of laminate wood. Guy cables.	Operational at limited wind speeds (2018).	[48,51,59]

Vertical Wind AB discontinued turbine development when they lost a key investor in 2010, and the 200-kW prototype was sold soon after to Uppsala University. However, Vertical Wind remains active in building generators for other wind turbine manufacturers.

4. Other Notable Swedish Contributions to Wind Turbine Development

Chalmers University of Technology been testing different solutions on their 40-kW wind turbine on Hönö in the Gothenburg archipelago since 1984 [32,60]. Both two- and three-bladed rotors with gearbox-equipped and direct-driven generators have been tested. Notably, in collaboration with Nordic Windpower, the blade profiles and hub assembly of Nordic's 400-kW turbine were tested on the Hönö turbine starting in 1991.

Launched in 2002, ABB developed a high-voltage, variable-speed, direct-driven, PM generator concept called Windformer, which was designed specifically for wind farms. It had one rectifier per wind turbine but only one inverter for the entire farm [61]. The Windfomer was planned to be tested in a ScanWind 3 MW at Näsudden when ABB suddenly canceled the program in 2002 [62]. Nonetheless, ABB is still a major component supplier for the global wind power industry [63]. Besides ABB, Swedish bearing manufacturer SKF is also a key player in the wind turbine subindustry [64]. Another serious attempt to design a direct-driven generator in Sweden was from NewGen, which in 2002–2008 designed and tested a direct-drive PM generator with the bearings adjacent to the air gap in a way that reduced the stiffness requirements of both the rotor and stator [8,65].

The company SeaTwirl AB has launched a concept with a floating VAWT H-rotor [66]. The entire turbine, including the under-water floating element, rotates, except for the generator house, which is anchored to the seabed, a solution where the bearing does not carry the weight of the turbine. SeaTwirl has tested a 10-m, 30-kW prototype in the sea just outside of Lysekil on the Swedish west coast and aims to construct a prototype of their planned 50-m, 1-MW model in 2020 [67].

5. Discussion and Conclusions

As illustrated in Figure 5, there has been ongoing activity with Swedish wind turbine developments since the start of the wind energy program in 1975. However, the Swedish position as a frontrunner in the late 1970s has gradually declined. After the time of large government-funded prototypes, several attempts were made to build commercial wind turbines in Sweden. The two largest attempts, ScanWind and Nordic Windpower, were partly devolved from the large governmental prototypes. These and other attempts in the 1980s to the early 2000s were commercially unsuccessful. More recent activity has focused on VAWTs, with the Vertical Wind 200-kW prototype built in 2010 and SeaTwirl's ongoing attempts with floating VAWTs. However, the magnitude of the Swedish VAWT activity is considerably smaller than the earlier horizontal axis wind turbine (HAWT) attempts where wind farms were constructed with MW-scale turbines. Although VAWTs have potential in niche markets, today, they are far from being ubiquitous in the broad commercial market, which also demonstrates Sweden's current position regarding wind power development and industry.

As apparent from Table 1, most of the Swedish wind turbines, up to ScanWind, had two blades, a feature that became synonymous with the Swedish wind turbine development line. The two-bladed turbines can, in most cases, benefit from a lighter construction which can be made cheaper. However, two-bladed rotors have an imbalance regarding the moment of inertia with respect to yawing, which is one of the reasons they usually have a teetering or flapping hub rather than a conventional rigid hub [68]. Today, the three-bladed wind turbine has become the essentially unchallenged standard for commercial large wind turbines.

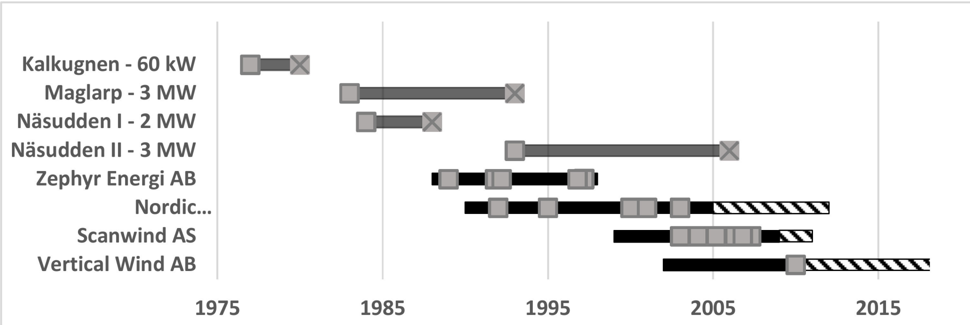

Figure 5. Timeline of the Swedish wind turbines. The markers represent erected turbines and for single turbines, decommissioning is also marked. Nordic Windpower's continuation in China and the USA, GE's continuation of ScanWind and Vertical Wind's inactive period have dashed bars.

The large prototypes in Maglarp and Näsudden all operated relatively well for hosting untested technology, with two out of three being world record holders for electricity generation from a wind turbine. During the time of the prototypes, Sweden had an advantageous position as a frontrunner regarding the setting up of a successive wind turbine industry. However, this was never taken advantage of, and instead, countries like Denmark and Germany soon established themselves as world leaders. In [6], it is argued that one important reason behind this is that that the domestic industry was not favored in government policies for deploying wind power. In addition, in Germany unlike Sweden, the political will to realize their wind energy plans was strong enough to counter the reluctance from power utilities. In [9], emphasis is also put on political policies with a focus on the 1980 nuclear power referendum and the following Parliamentary decision to continue relying on nuclear power for the coming decades. This led to a disinterest in wind power and to the 1985 cancelation of the first and more generous phase of the Swedish wind energy program. In [5], it is argued that early government interventions that limited the number of actors and focused the development on large two-bladed prototypes was a reason for not succeeding. On the contrary, in [8], the two-bladed line and large prototypes are defended, and instead the political disinterest following the nuclear referendum, the reluctance of power utilities, and the unfavored domestic market are mentioned.

Funding: This research received no external funding.

Acknowledgments: This work would not have been possible without valuable input from several people involved in different projects, for example sharing personal experience, images, and other material. The author would like to give a special thanks to Staffan Engström. In addition, thanks go to Göran Sidén, Gunnar Britse, Jens Melin, Fredric Ottermo, Leif Svensson, Lennart Nilsson, Bengt Göransson, John Strand, Andreas Johansson, Tomas Lyrner, Jos Beurskens, Anders Wickström, Stefan Ivarsson, Pål Anders Dahl, Stina Albing, Sven-Erik Thor, and Anders Bjarnehag.

Conflicts of Interest: The author declares no conflict of interest.

References

1. Musgrove, P. *Wind Power*; Cambridge University Press: Cambridge, UK, 2010.
2. Gipe, P. *Wind Energy for the Rest of Us: A Comprehensive Guide to Wind Power and How to Use It*; Wind-Works.Org: Bakersfield, CA, USA, 2016.
3. Bränsleförsörjningen i atomålden: Betänkande avgivet bränsleutredningen 1951. Del II. In *Handelsdepartementet, Ed*; Iduns tryckeriaktiebolag Esselte Konsult AB: Stockholm, Sweden, 1956.
4. Ackermann, T.; Söder, L. An overview of wind energy-status 2002. *Renew. Sustain. Energy Rev.* **2002**, *6*, 67–127. [CrossRef]
5. Åstrand, K.; Neij, L. An assessment of governmental wind power programmes in Sweden—Using a systems approach. *Energy Policy* **2006**, *34*, 277–296. [CrossRef]
6. Bergek, A.; Jacobsson, S. The emergence of a growth industry: A comparative analysis of the German, Dutch and Swedish wind turbine industries. In *Change, Transformation and Development*; Springer: New York, NY, USA, 2003; pp. 197–227.

7. Bergek, A. Shaping and Exploiting Technological Opportunities: The Case of Renewable Energy Technology in Sweden. Ph.D. Thesis, Chalmers University of Technology, Gothenburg, Sweden, 2002.
8. Engström, S. *Historien Om Den Svenska Vindkraften—Hur det Började. Läget idag. Framtid*; Ägir Konsult AB: Stockholm, Sweden, 2015.
9. Carlman, I. Blåsningen—Svensk Vindkraft 1973 Till 1990. Ph.D. Thesis, Uppsala University, Uppsala, Sweden, 1990.
10. *Vindenergi i Sverige: Resultatrapport juni 1977*; Liber: Stockholm, Sweden, 1977.
11. *Vindenergi: resultat, utvecklingsläge och förutsättningar: resultat av verksamheten inom området Vindenergi*; Liber: Stockholm, Sweden, 1981.
12. Windheim, R. *LS - WECS: Second Annual Report (1979)*; International Energy Agency: Stockholm, Sweden, 1980.
13. *Vindkraft—Resultat Och Slutsatser Från det Svenska Vindenergiprogrammet*; Statens Energiverk Report 1985:1; Liber: Stockholm, Sweden,, 1985; Volume 1985, p. 1.
14. The History and Heritage of Vattenfall. Available online: https://history.vattenfall.com/from-hydro-power-to-solar-cells/the-evolution-of-wind-power (accessed on 19 February 2019).
15. Forsgren, M.; Back, T. *Försöksanläggning för vindkraft: Kalkugnen 1977-1980: Sammanfattning av resultaten från verksamheten*; NE: Stockholm, Sweden, 1983.
16. Magnusson, M.; Smedman, A.-S. Air flow behind wind turbines. *J. Wind Eng. Ind. Aerodyn.* **1999**, *80*, 169–189. [CrossRef]
17. Lissaman, S.P. Energy effectiveness of arbitrary arrays of wind turbines. *J. Energy* **1979**, *3*, 323–328. [CrossRef]
18. Baldwin, D.H.; Kennard, J. *Development of Large, Horizontal-Axis Wind Turbines*; NASA-TM-86950; USA Department of Energy: Washington, DC, USA, 1985.
19. Bussolari, R. *Status of the 4 MW WTS-4 Wind Turbine*; Hamilton Standard Division of United Technologies: Windsor Locks, CT, USA, 1982.
20. Wind Turbine Systems. In Swedyards, Ed. 1982. Available online: http://www.windsofchange.dk/ (accessed on 19 February 2019).
21. *Erfarenheter Från Vindkraftverken vid Maglarp och Näsudden*; Stockholm; Allmänna förl: Stockholm, Sweden, 1990.
22. *IEA Wind Energy Annual Report 1993*; International Energy Agency: Stockholm, Sweden, 1994.
23. Svensson, G. Experiences from the commissioning and operation of the Swedish 2 MW WTS protptypte, Naesudden. In Proceedings of the EWEC'84—European Wind Energy Conference 1984, Hamburg, Germany, 22–26 October 1984; pp. 158–164.
24. Mets, V.; Hermansson, O. Status and experience with the 2Mw Wts 75 at NäSudden, Gotland. *IEE Proc. A Phys. Sci. Meas. Instrum. Manag. Educ. Rev.* **1983**, *130*, 542–549. [CrossRef]
25. *IEA Wind Energy Annual Report 1991*; International Energy Agency: Stockholm, Sweden, 1992.
26. Högström, U.; Asimakopoulos, D.; Kambezidis, H.; Helmis, C.; Smedman, A. A field study of the wake behind a 2 MW wind turbine. *Atmos. Environ.* **1988**, *22*, 803–820. [CrossRef]
27. Albers, C.; Hinsch, J.; Gabriel, J.; Klug, H.; Ronsten, G.; Simonssen, B. Comparison of power performance and noise between Aeolus 2 and Naesudden 2. In *EUWEC'96*; NUTEK: Gothenburg, Sweden, 1996.
28. Hållén, J. Matilda Faller för Framtidens Vindkraft Ny Teknik. *Ny Teknik*. 2008. Available online: https://www.nyteknik.se/energi/matilda-faller-for-framtidens-vindkraft-6421192 (accessed on 19 January 2019).
29. Sidén, G. *Utveckling av nya vindkraftverk i Falkenberg*; Energy in Minds! Falkenberg Energi AB: Falkenberg, Sweeden, 2010; Available online: hh.diva-portal.org/smash/get/diva2:376479/FULLTEXT01.pdf (accessed on 20 February 2019).
30. New Design on Market. *Wind Power Monthly*. 1994. Available online: https://www.windpowermonthly.com/article/958473/ (accessed on 19 February 2018).
31. *Handbok—Vindkraftverk Zephyr WTS 28.250*; Zephyr Energi AB: Falkenberg, Sweden, 1993.
32. *IEA Wind Energy Annual Report 1992*; International Energy Agency: Stockholm, Sweden, 1993.
33. *IEA Wind Energy Annual Report 1997*; International Energy Agency: Golden, CO, USA, 1998.
34. Zephyr Develops 750 KW Turbine. *Wind Power Monthly*. 1994. Available online: https://www.windpowermonthly.com/article/951913/ (accessed on 19 February 2018).
35. Innovative 20 kW from Pitch Wind. *Wind Power Monthly*. 1997. Available online: https://www.windpowermonthly.com/article/957164/ (accessed on 19 February 2018).

36. Engström, S.; Bergkvist, B.; Dalén, G. Evaluation and commissioning of Nordic 400 and 1000 prototpes. In *1996 European Union Wind Energy Conference*; H.S. Stephens & Associates: Gothenburg, Sweden, 1996; pp. 219–222.
37. Thor, S.; Dalen, G. Evaluation of Lyse wind power station 1992-1995. Final report. NUTEK-VIND-96-11, Projektrapporter-NUTEK VIND: (*Sweden*). 1996. Available online: https://www.osti.gov/etdeweb/servlets/purl/382436 (accessed on 20 February 2019).
38. *IEA Wind Energy Annual Report 95*; International Energy Agency: Golden, CO, USA, 1996.
39. Euopean Commission. *Demonstration of Nordic 1000 Wind Turbine*. 1999. Available online: https://cordis.europa.eu/project/rcn/45312_en.html (accessed on 19 February 2019).
40. *IEA Wind Energy Annual Report 2000*; International Energy Agency: Golden, CO, USA, 2001.
41. *IEA Wind Energy Annual Report 2001*; nternational Energy Agency:: Boulder, CO, USA, 2002.
42. *IEA Wind Energy Annual Report 2005*; International Energy Agency: Boulder, CO, USA, 2006.
43. Koepp, P. Turbine-maker Nordic Windpower Files for Liquidation Bankruptcy. *Kansas City Business Journal*. 2012. Available online: https://www.bizjournals.com/kansascity/print-edition/2012/10/19/turbine-maker-nordic-windpower-files.html (accessed on 20 February 2019).
44. *IEA Wind Energy Annual Report 2004*; International Energy Agency: Boulder, CO, USA, 2005.
45. Karlberg, L.-A. Nytt haveri för Scanwinds vindkraftverk i Norge. *Ny Teknik*. 2009. Available online: https://www.nyteknik.se/energi/nytt-haveri-for-scanwinds-vindkraftverk-i-norge-6408383 (accessed on 20 February 2019).
46. Knight, S. Norwegian project hit by Scanwind turbine write-off. *Wind Power Monthly*. 2013. Available online: https://www.windpowermonthly.com/article/1180581/norwegian-project-hit-scanwind-turbine-write-off (accessed on 20 February 2019).
47. Smith, P. GE 4.1 Turbine to be Kept in Operation. *Wind Power Offshore*. 2014. Available online: www.windpoweroffshore.com/article/1288922/ (accessed on 19 January 2019).
48. Apelfröjd, S.; Eriksson, S.; Bernhoff, H. A Review of Research on Large Scale Modern Vertical Axis Wind Turbines at Uppsala University. *Energies* **2016**, *9*, 570. [CrossRef]
49. Möllerström, E.; Gipe, P.; Beurskens, J.; Ottermo, F. A historical review of installed vertical axis wind turbines rated 100 kW and above. *Renew. Sustain. Energy Rev.* **2019**, *105*, 1–13. [CrossRef]
50. Möllerström, E.; Ottermo, F.; Hylander, J.; Bernhoff, H. Eigen Frequencies of A Vertical Axis Wind Turbine Tower Made of Laminated Wood and the Effect Upon Attaching Guy Wires. *Wind Eng.* **2014**, *38*, 277–290. [CrossRef]
51. Möllerström, E.; Ottermo, F.; Goude, A.; Eriksson, S.; Hylander, J.; Bernhoff, H. Turbulence influence on wind energy extraction for a medium size vertical axis wind turbine. *Wind Energy* **2016**, *19*, 1963–1973. [CrossRef]
52. Möllerström, E.; Ottermo, F.; Hylander, J.; Bernhoff, H. Noise emission of a 200 kW vertical axis wind turbine. *Energies* **2016**, *9*, 19. [CrossRef]
53. Ottermo, F.; Möllerström, E.; Nordborg, A.; Hylander, J.; Bernhoff, H. Location of aerodynamic noise sources from a 200kW vertical-axis wind turbine. *J. Sound Vib.* **2017**, *400*, 154–166. [CrossRef]
54. Maegaard, P.; Krenz, A.; Palz, W. *Wind Power for the World: The Rise of Modern Wind Energy*; Pan Stanford Publishing: Singapore, 2013.
55. Agrell, M. Report fom WTS-3 Maglarp, one year of operation. In Proceedings of the EWEC'84—European Wind Energy Conference 1984, Hamburg, Germany, 22–26 October 1984; pp. 152–157.
56. KAMEWA—Wind Turbine Systems. In 1981. Available online: http://www.windsofchange.dk/ (accessed on 19 February 2018).
57. Ulén, E. *Lyse Vindkraftstation—Drivlina och Reglering*; Flygtekniska Försöksanstalten: Bromma, Sweden, 1995.
58. *IEA Wind Energy Annual Report 1994*; International Energy Agency: Golden, CO, USA, 1995.
59. Möllerström, E. Noise, Eigenfrequencies and Turbulence Behavior of a 200 kW H-Rotor Vertical Axis Wind Turbine. Ph.D. Thesis, Uppsala University, Uppsala, Sweden, 2017.
60. Ellsén, M.; Carlson, O. *Teknisk Slutrapport i Projektet: Drift av Hönö Provstation—HÖNÖ*; Chalmers University of Technology: Gothenburg, Sweden, 2006.
61. Dahlgren, M.; Frank, H.; Leijon, M.; Owman, F.; Walfridsson, L. Windformer-Vindkraften blir storskalig. *ABB Tidning*. 2000. Available online: https://library.e.abb.com/public/8e45345edc5dab08c1256ddd00346fa9/31-37%20M153.pdf (accessed on 20 February 2019).

62. Technology claims never realised - ABB cancels Windformer. Wind Power Monthly. 2002. Available online: https://www.windpowermonthly.com/article/958802/technology-claims-realised---abb-cancels-windformer (accessed on 20 February 2019).
63. Products and sevices for wind turbines. In *Electrical direvetrain solutions and products for turbine subsystems*; ABB: Zurich, Switzerland, 2010; Available online: www.abb.com/windpower (accessed on 20 February 2019).
64. Top 5 Vendors in the Wind Turbine Bearing Market from 2016 to 2020: Technavio. Available online: https://www.businesswire.com/news/home/20161012005036/en/Top-5-Vendors-Wind-Turbine-Bearing-Market (accessed on 7 December 2018).
65. Engstrom, S.; Lindgren, S. Design of NewGen direct drive generator for demonstration in a 3.5 MW Wind Turbine. In Proceedings of the EWEC European Wind Energy Conference & Exhibition, Milan, Italy, 7–10 May 2007.
66. SeaTwirl. Available online: https://seatwirl.com/ (accessed on 19 February 2019).
67. Sea Twirl Investigates Vertical Axis Turbine Designs. *offshoreWIND.biz*. 2018. Available online: https://www.offshorewind.biz/2018/05/23/seatwirl-investigates-vertical-axis-turbine-designs/ (accessed on 19 February 2019).
68. Manwell, J.F.; McGowan, J.G.; Rogers, A.L. *Wind Energy Explained: Theory, Design and Application*; Wiley: Chichester, UK, 2010.