Wind Power Automation Technology in Historical Perspective: From Pre-Industrial European Windmills to Inter-War Automatic American Wind Generators

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Abstract

This article reviews historical experiences with wind energy technologies in order to draw observations regarding the history and philosophy of regulating (control, automation) devices. Based on the work of T. Lindsay Baker and Robert Righter, it invites attention to the history of the millions of successful autonomous pre-war and inter-war wind structures that were manufactured and used in the United States, mostly on American farms, for grinding, pumping and for the generation of electricity. They represent the climax in the use of stand-alone wind power structures. Stand-alone wind generators stand at the opposite end of the grid-connected wind farms of the last three decades, which tend to reproduce the industrial model of electricity generation. This paper is focused on the sustainability of these stand-alone structures, as exemplified by the self-regulating arrangements that were integrated into them. It represents a first attempt at defining a sustainable energy technology by considering a suggestive case that exhibits the successful blending of energy and automation technologies.

From the 'Old World' windmills to the 'New World' self-regulating windmills

The industrial revolution of steam power did not replace all previous forms of energy generation. Waterpower in particular remained the primary energy source up until the 1870s, the period known as high industrialization. In the monarchic and ecclesiastic Middle Ages, watermills formed part of inherited land property. In this feudal organization of space the watermill was exploited monopolistically. Parallel to this, there is another history of energy production that was frequently monopolized but also resisted submitting to the feudalist social system: the long history of the windmill. European horizontal axis windmills, which could be turned to face the wind, were used for grinding grain since the twelfth century, from the western coasts of the Continent to Minor Asia, and from the British Isles to the Mediterranean. Vertical axis windmills were used in Persia and Central Asia since the tenth century, and as Lynn White writes, they could also be found in Tibet, where they were used as prayer wheels. These Asiatic windmills had a ball-and-chain governor that regulated their rotation. Other labour-saving windmill designs were the white canvas-sail flour-grinding windmills in the Cyclades (White 1964).

The Dutch pumping windmills emerged as a technological innovation out of the Golden Age of the Netherlands, and were used for land reclamation. They accompanied its development up until industrialization. The four-blade tower windmill with the canvas sails was by far the most complex machine until the advent of the steam engine. The Dutch windmill was part and parcel of local communities, where the work of the millwright was extremely important. The millwright was connected to a network of other windmill-related professions such as carpenters, blacksmiths, and sailmakers. The tower-mill and the smaller post-mill were the dominant designs in the Netherlands and Great Britain respectively. In Great Britain the post-mill emerged as a form of resistance to the monopolistic watermills owned by the landlords. In general, the windmill was a symbol of freedom and independence from feudal authorities (Davids 1998; Righter 1996).

Matthias Heymann, expert in the history of wind energy, described the toil of both Dutch and German millwrights, who had to take off the sails every time the wind became too strong, and then put them back again, which could happen many times a day, depending on the circumstances. The millwrights did not only need a good sense for the quality of the wind and for the way the weather was developing, but also had to turn the mill to face the wind by manoeuvring a steering mechanism, which moved the heavy roof structure and thus rotated the mill. In the context of pre-industrial Europe the dexterity of the millwright stemmed from centuries of accumulated and slowly diffused tacit knowledge. In the German regions the expansion of the windmill evolved slowly from the sixteenth to the nineteenth century, due to the bans that had been imposed on the construction of windmills. The milling bans were first abolished in 1810 in Prussia and then in 1870 during Bismarck's administration in all of the German states (Heymann 1995).

English and French-speaking immigrants had transferred windmill technology and knowledge to the east coast of the New World as early as the mid-seventeenth century. However, the heavy and costly structures of the old-style windmills, and especially their permanent need for attendance and maintenance posed severe constraints to the diffusion of their use (ibid.). In the colonies of the New World, where labour was scarce, the cumbersome and immovable European-style windmills were not a widely preferred choice. Most farmers and ranchers striving to survive within subsistence economies could not afford to build them, let alone regulate and maintain them. The Dutch founders erected a number of the old-style windmills in New Amsterdam, and English settlers constructed post-mills for grinding grain at Long Island. 'Windmills of the European variety were the exception rather than the rule – perhaps cultural reminders of the Old World', argued Robert Righter, 'they were not essential to the New. In the colonial period and the decades leading up to the Civil War, Americans created energy through human and animal labour, wood, and water' (Righter 1996, 22). In contrast to the association of the windmill to a free energy source related to the merchant economic development in Central Europe (Flanders, Southern and Northern Netherlands), the colonial use of the waterwheel paired well with the feudalistic power relations that were reproduced in the southern colonies:

> In the northern colonies, the waterwheel assisted in the development of small businesses and the capitalist system, decreasing the need for backbreaking human labor or animal toil. In the southern colonies, however, waterwheels contributed to a failed feudalistic order that was being supplanted by a slave-holding society. As in England, the capturing of energy from water lent itself to monopoly and antiegalitarian tendencies, simply because it was concentrated (and therefore

> manageable), rather than diffuse. Historian Larry Hasse maintains that the waterwheels of the South served well the planter aristocracy intent on maintaining and nurturing a slave-labor system. (Righter 1996, 20)

After the decline of this social system new constraints were imposed upon the development and use of wind power technology. The European-style windmill was gradually losing ground to the steam engine on the continent from the 1850s to the 1900s. The small scale, the large fluctuations in wind, and the poor output of the Old-World windmills could not match the developing steam-powered industries.

By the early nineteenth century the Scottish engineer James Watt had been informed about the centrifugal governor, a mechanical device that had been used for at least two centuries in Britain for regulating the gap between the millstones in some windmills. The sails activated a rope that constantly turned the governor weights by means of centrifugal force and pushed them outwards thus raising a boss that was attached to the millstone. Watt embedded this mechanical self-regulator into the steam engine in order to regulate the movement of the throttle valve that opened and closed the passage of steam from the boiler to the cylinder. However, governors could not be used – and were not used – universally. For example, steam engines used for pumping had to be manually regulated because of the large fluctuations in load, or in steamboats where the governors were unsuitable because of the dependence of the governor weights on gravity (Hunter 1979; 1985).

Dutch and British innovations had made the windmill the most important pre-industrial prime mover next to the watermill. One of these key developments was the fantail, which had long been used in Britain to automatically bring the wheel into the wind. Another was the self-acting shuttered sail that could withstand stronger winds by means of a regulatory system that opened and closed the sail. Despite the fact that self-regulatory mechanisms were well known and used in certain regions of Britain, they were not suited for all uses of wind power. The windmills used for pumping water for example, had to deal with great variations in load or resistance and could not be regulated by the common mechanical governor.

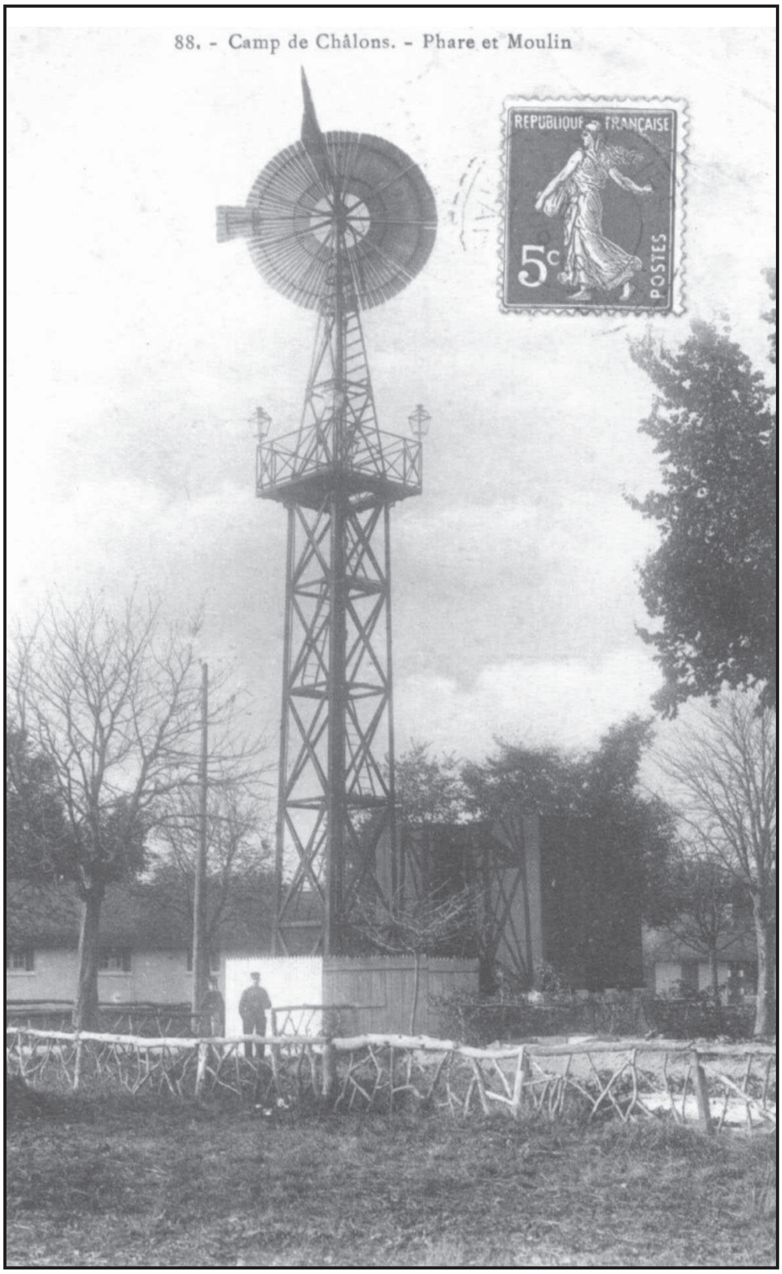
In his 1998 article Karel Davids investigated the validity of Otto Mayr's hypothesis in relation to the absence of self-regulation in the Dutch windmills. According to Mayr's hypothesis, self-regulating mechanisms belonged to a liberal social conception of order, which solely existed in Great Britain by the turn of the nineteenth century (Mayr 1986). Davids examines the various interested social actors that could have prevented the use of self-regulating mechanisms in the old-style windmills, and examines some cases of possible resistance from operators. Davids also writes that a technical difficulty might have been responsible for the lack of automation in Dutch drainage windmills, a factor that was the case in similar windmill usage on the British Isles. He argues:

> The use of self-acting mechanisms in drainage windmills, which reacted merely to the wind, would under these circumstances have been a nuisance rather than a bonus. Mills would have persisted with draining water as long as wind speed allowed, even if the mark in the boezem [drainage canal] had been exceeded. The application of self-regulating mechanisms on these mills would solely have made sense if they had not just been tuned to the wind, but also to the level of the water in the general reservoir. (…) As long as this device did not exist, landowners and land-users in the Netherlands could only have dispensed with human operators at their peril. (Davids 1998, 241)

Nevertheless, the unprecedented development in the manufacture and use of automatic windmills came neither from the Netherlands nor from Great Britain, but from the other side of the Atlantic. It was also a development parallel to the expansion of the use of steam power in the United States. This expansion moreover did not remain confined within the US borders. Following the Columbian Exhibition at Philadelphia in 1876 American windmills were consistently exported to Central and South America, to Australia, Tunisia and surprisingly enough to Germany and Scotland (Baker 1985; Douglas & Oglethorpe 1984; 1986).

The vast flat area of the American Great Plains was a harsh environment in which to live, especially due to the lack of running water. A great number of automatic windmills were installed in the Western and Midwestern regions and used for pumping and lifting water for household and livestock supply. Grinding grains for feeding animals was also a very common use of power windmills.

Figure 1.



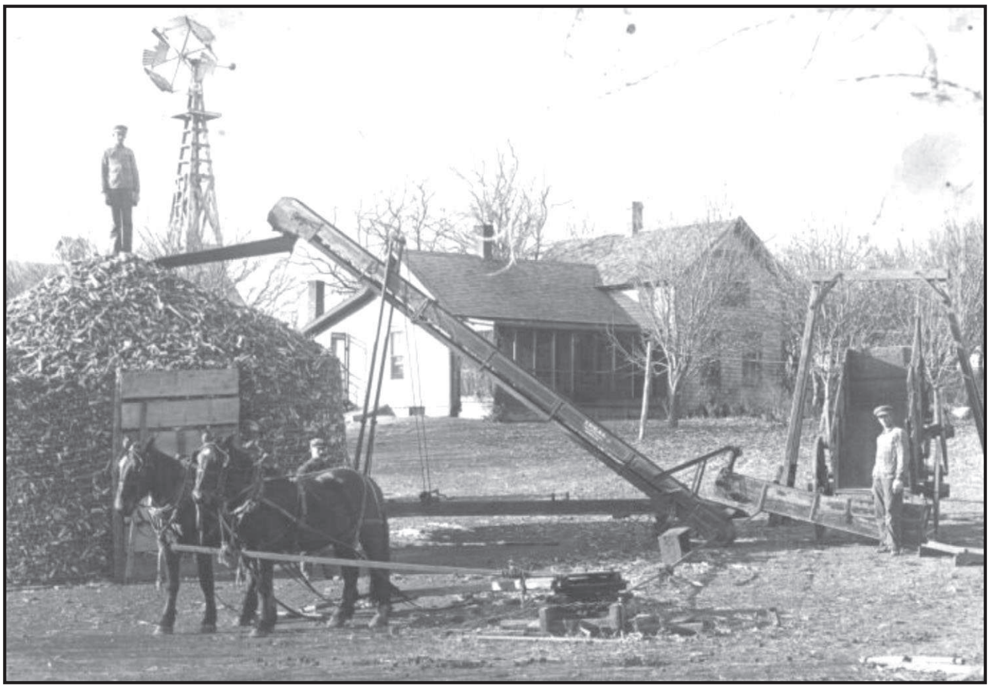
An Eclipse or Corcoran solid-wheel wooden windmill pumping water for a military garrison located at Camp de Châlons, France, circa 1915. Taken from the Gallery of photos in the Windmiller's Gazzette at http://www.vintagewindmills.com {19 February 2011}.

Windmills were also ‘connected’ in parallel to the railways, the first large technical system of industrial capitalism. They were used at the railway stations along the transcontinental rail lines for pumping and lifting clean water to large elevated tanks supplying the boilers of the locomotives. This was a very important issue in itself, since minerals could lead to boiler erosion, which in turn caused catastrophic steam boiler explosions. These windmills were heavy-duty large machines, sometimes even thirty meters in diameter, that worked all day to fill the reservoirs. One of the most common railroad-pattern windmill was the Railroad Eclipse, manufactured by the Eclipse Wind Mill Company. This use continued as late as the mid-twentieth century when steam locomotives were replaced by diesels (Baker 2007).

In around 1900 large-diameter windmills were built for public use next to wells with local government funding in municipalities such as Kansas City, and in several towns in Nebraska. These windmills supplied water to horses and mules. They had automatic float valves connected to regulators which turned on and off when the water level in the tanks became too low or too high. Some communities had constructed their own town-scale water works systems by erecting power wind pumps, which also supplied piped drinking water for local residents (ibid.).

Other industrial uses of windmills included cutting fodder, sawing wood, shelling corn, and powering smaller machines like lathes and churns, and even printing presses for newspaper production. The majority of the power engines used in the windmill manufacturing industry were heavy steam-powered machine tools like cutters and punchers. The size of the windmills manufactured varied. The twelve to fourteen feet diameter windmill had the biggest market share, but some much larger mills were also available for many years. For example, the Empire Mill Manufacturing Company produced seven thirty-feet diameter windmills at Syracuse, New York, as early as 1873. These were built and exported for ore reduction on the Island of Oruba in the West Indies, where high winds and high fuel prices made the windmill economically attractive (Baker 1985).

Figure 2.



Original Monitor Vaneless wooden vaneless pumping windmill on custom wooden tower on a farm perhaps in eastern Kansas, USA, ca. 1910.
At http://www.windmillersgazette.com/images/photo34.jpg {19 February 2011}.

The most commercially successful automatic windmill was the work of a young mechanic and New England Yankee, Daniel Halladay. Halladay contributed to the commercial celebration of one of the most successful windmills of the post-bellum period: the Halladay Standard. The Halladay Standard model, a windmill used primarily for pumping water, was an archetypal machine, the most successful section-style windmill manufactured in the United States at the turn of the nineteenth century by the US Wind Engine and Pump Company. The two most common styles of wheels at that time were the section wheel and the solid wheel, i.e. a folding and a fixed wheel. In terms of regulation, the section-wheel windmill would regulate the surface area of the blades that faced the wind by opening and closing like an umbrella. This was performed by a governor weight connected with a linkage mechanism to the wheel sections. In other words, equilibrium was achieved between the tendency of the sections to turn away from the wind direction and their tendency to return to the position of facing the wind. The solid-wheel style was part of the very successful Eclipse model, which was manufactured until the 1920s and used for grinding grain. Although most windmills were vaneless, this model used an extra side-vane after the 1870s that pushed the wheel away from the wind, while this was balanced by a weighted lever through a linkage system (Baker 1985).

Next to self-regulation, accumulating wind energy was an issue in itself. This was usually done by means of compressed air and the lifting of water or sand, before batteries came to be used in connection to the electricity wind generator. Batteries were surely an expensive means of energy storage. In addition, wooden bearings were replaced by steel bearings with the result that lubrication became a problem (Baker 1985; 2007).

Oiling was a very laborious job that involved climbing up the very high windmills. Windmill owners were constantly complaining about the need of lubrication on a weekly basis. The most notable innovation at the time was an oil canister or tin placed above the bearings, which could be operated from the ground by pulling a wire. Although it did not entirely substitute the need to climb up and refill it, it made this job a less frequent necessity. In the 1900s the new self-oiling windmills had a closed oil-bath reservoir, and hit success (ibid.).

All in all, automatic arrangements eliminated many painstaking and laborious duties related to the working and maintenance of mechanical windmills. They made it possible for the farmer, the rancher and their families to employ wind energy for their everyday work. So important were they that the dangerous and manly profession of the windmiller was considered to rank with that of the teacher, the preacher and the doctor in the sparsely populated western states. In many instances the tools needed for windmill installations and repairs were owned by one family in the area and were lent for use to the families of the local community (Beck 2000). The successful development and use of self-regulating devices contributed significantly to the widespread employment of wind structures.

Independent wind generators vs. the grid

The first attempts to manufacture viable wind generators for direct current electricity production faced significant difficulties and did not flourish until the 1920s. One of these attempts came from the Lewis Electric Company of New York. The company produced some of the first working independent wind generators for lighting purposes at the turn of the twentieth century. These were strategically aimed at the upper middle-class market. The gardens of suburban middle-class homes had the necessary space for installing a wind generator. The company only managed to sell a few units, however, and soon went out of business. Some other windmill companies like the Aermotor Company and Fairbanks, Morse and Company followed this start with better results. The latter being the manufacturers of the very successful Eclipse mill, managed to convert it by adding a small dynamo and batteries for accumulating the converted energy. However, the fin-de-siècle wind generators performed poorly. It was not until the inter-war period when further modifications took place that electricity produced from the wind began to compete with the local electricity cooperatives supported by REA (Rural Electrification Administration) (Righter 1996).

In technical terms, the main problem with respect to performance was the deficiency in the number of revolutions of the wind blades. To use the popular proverb, an ill wind blows no good. Further improvements in blade design came with the aircraft developments during World War I. The US government aircraft program in 1917 and the incremental innovations that followed, contributed to a more efficient wind generator design (ibid.). The free disposal of the wind and the accumulated knowledge of the 1920s met the renewal in popular demand for wind-generated electricity. After the First World War, electricity and electrical household appliances had already begun to pervade farm households.

A new generation of American wind electricity companies capitalized on the design innovations. The new machines started to compete with the gasoline farm-lighting plants and with fossil fuel dependence. Righter states that by 1920 some forty-three percent of the farmers in Utah and twenty-five percent of California farmers were connected to the grid, but the vast majority of the rural West and Midwest regions were not. As electricity was becoming indispensable for the new way of life, wind generators seemed a more attractive investment. The capital needed to buy such a machine at that time was comparable to that needed for buying a car. Credit schemes were available with a scaled interest of seven to fifteen percent for a one-year period of quittance. The cost for postage and installation of the heavy machines (one to two tons with the tower structure) was also considerable. Due to some post-war fossil-fuel crisis episodes, there was an increase in electricity generating wind installations:

> In the city and on the farm, petroleum-dependent systems replaced renewable fuel systems. Farmers on the West Coast became particularly aware of this dependence in 1920, when a shortage of both petroleum and energy occurred. That summer, a drought created a deficit in hydroelectricity; simultaneously, for four months, petroleum was uncommonly scarce. This brief episode alarmed farmers, who realized that centralization, with all its advantages, was not flawless, and energy self-sufficiency might be more reliable. (Righter 1996, 84)

By the end of the 1920s the market was ready for new and better models. A man who had grown up on a farm in North Dakota, Marcellus Jacobs founded a company together with his brother Joe that constructed and sold thousands of these inter-war wind generators. The company moved from Montana to Minneapolis in 1930, where it experimented with new designs for over ten years. The Jacobs model was a successful combination of a series of parts that were already available. The mechanical part of the wind-power arrangement, the fan, acted as an energy collector. The regulating device, a fly-ball governor, had already been used in electricity generating steam engines. The Jacobs brothers arranged the governor in such a way that it controlled the rotation of the blades about their axis so that the resistance to high winds was diminished. The electrical part was a construction of a battery arrangement. The fan was replaced by the new technology of the helix, which was the fruit of the aeronautical developments of the era. The Jacobs Wind Electric Company produced robust 32-volt and 110-volt DC electricity wind generators with three blades, with a rated power of

1.8 kW, 2.5 kW, and 3 kW. They had a variable-pitch rotor with Sitka Spruce blades (these were maintained in the new models when the company was reopened in the mid-1970s), and a direct-drive generator. In particular, the special adaptation of the mechanical regulator to the Jacobs wind generators made these machines the best of their kind.[1]

The US army installed one of these in the polar environment of Antarctica, forgot all about it, and twenty-two years later it was found to be still working without any problems even though the blades were covered by several meters of snow. Marcellus Jacobs was very proud of this wind generator. He claimed to be a kind of a 'freak' who wanted his machines to last for a lifetime (Righter 1996, 90). Despite the moderate price and the viability of Jacobs' wind generators, the unfolding of the Great Depression took its toll on the sales. Acquiring one of these state-of-the-art Jacobs wind generators became a distant dream for many farmers who had to settle for a cheaper solution. In the end, the factory had to shut down in 1956 under the pressure of centralization, the electrical companies' monopolies, the declining prices of electricity and the pervasion of the grid.

While the Jacobs wind generator was the 'Cadillac of wind machines', the one manufactured by the Wincharger Corporation was its 'Model T' equivalent. The difference between the two was above all a difference in self-regulation. Where the Jacobs model had a variable-pitch governor that feathered the blades in high winds, the governor on the Wincharger could not minimize the resistance of its fixed four blades to the wind. Despite the problematic self-regulation of the latter, their lower price and the larger range (6, 12, 32, and 110 volts) helped the company to acquire a large share in the wind plant market of the 1930s. Later models used variable pitch for two of the four blades (Righter 1996, 101). In particular, the low-cost 6-volt wind generator was a prime choice for charging radio batteries on family farms, with radio having been the most important communication medium on the Great Plains in the years of the Great Depression. By the end of 1938 the company had sold 750,000 wind generators worldwide (Sagrillo 1992).

Figure 3.

Marcellus Jacobs posing on top of his 2.5kW wind-generator. Picture taken from http://www.wincharger.com/jacobs/jacobsphoto.jpg {19 February 2011}.

In spite of the difficulties, the number of wind machines installed remains striking. Righter estimates that in the United States alone they surpassed the five million mark during the inter-war period. Over one million were individual wind generators that provided electricity for the everyday needs of the farms – for lighting and the radio. They were installed and satisfactorily used on farms and ranches in the Western and Midwestern states of America, until they were removed – not without resistance – in the late inter-war period during Franklin Roosevelt's administration, when farms were first subjected to the democratic control of the rural electrification cooperatives and soon after this to the central power system (Righter 1996). As Righter narrates:

> While government generously supported research and development for central power systems and the "hard energy path" (coal, petroleum, natural gas, nuclear), from the 1920s through the 1960s those companies, inventors, and individuals who advocated alternative energy received no assistance and precious little encouragement. (Righter 1996, 86)

> [In 1945] Weinig [the vice president and general manager of Wincharger Corporation] suggested that H. R. 1742 (the rural electrification legislation) be amended so that the REA program would provide ten-year, low-interest loans to farmers and ranchers for individual energy plants in sparsely settled areas. (…) 'Would you propose', asked Hinshaw, 'that the REA own and rent the equipment or that they merely finance the ownership of the equipment on a chattel mortgage?' (…) Weinig made a respectable presentation (…) but his efforts were in vain. Legislators abandoned the amendment. Essentially, Weinig could find no support among the nation's energy brokers. The Rural Electrification Administration, the Tennessee Valley Authority, and the utility companies were wedded to central power systems. (Righter 1996, 122)

In contrast to the boldly subsidized large-scale, centralized and monopolized grid, an individual wind generator required from its owner a capital equivalent to that needed for buying an average car in the same period. Maintenance was usually provided at minimum cost either by the owner himself or a windmiller with no more than a working day's wage once a month or so. By contrast, the gigantic units proposed by the promoters of centralization for the large-scale exploitation of wind energy, required high-cost installation and maintenance. As Mick Sagrillo put it, utilities and electric cooperatives 'refused to provide utility power to farms that were serviced by working wind generators' (Sagrillo 1992). Regrettably, most of these autonomous units were destroyed, sold as scrap or left to rust away, forcing farmers and ranchers to submit to an even larger degree to the capitalist mode of energy production.

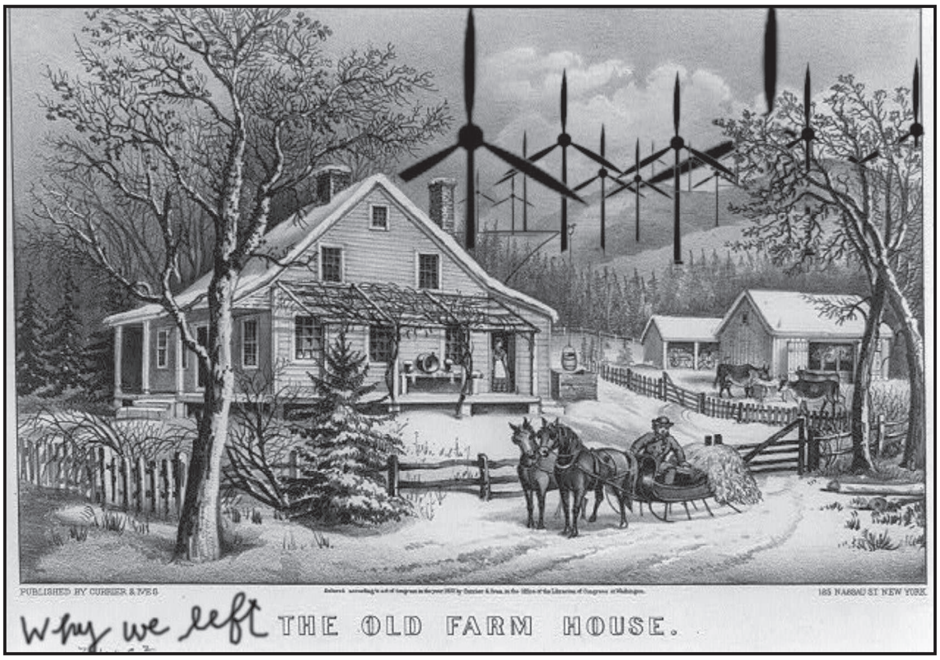
Observations regarding sustainability

The recent historiography of wind energy has largely ignored the history of inter-war wind generators, restricting its perspective either to traditional wind arrangements or to some spectacular – but totally unsuccessful – post-war experiments with gigantic wind generators. Denmark, the country that maintained a tradition of small-scale, community-owned wind generators throughout the twentieth century, found itself in a better position in this field during the post-war period than Germany or the United States, which led the post-war experiments in large-scale wind-power production. Consequently, the global market of the 1980s and 1990s, even California, was flooded with Danish wind generators (Heymann 1998).

The history of electrification as written by Thomas Hughes in *Networks of Power*, assumes a rational and evolutionary course to a supposedly technically superior technology of long-distance networks of electrical power transmission. The history of the pre-war autonomous windmills and the inter-war independent wind generators, on the other hand, presents a picture of constant competition between different technological versions, which served different and competing orientations of social organization. Those versions that prevailed technically and socially did not necessarily represent the best possible outcome. The decisive element was, ultimately, the intervention of governmental policies favouring certain versions of electrification, e.g. huge dams for hydro-electric power projects, instead of small autonomous wind generators (Tympas 2009).

The millions of wind generators on family farms in the United States, and the hundreds of thousands of units in use around the world, that provided electricity for lighting or the radio, illustrate a very different strategic policy to that behind contemporary wind farm installations. They call for the drawing of a demarcation line between wind farms and individual wind generators, with the first being grid-connected and state and/or corporate-owned, while the latter are autonomous and family or community-owned.

Figure 4.



This picture accompanied a letter written in July 2010 by a disappointed farmer who had to leave his farm after the installation of a wind farm. At http://betterplan.squarespace.com/todays-special/2010/7/26/72610-triple-feature-from-open-arms-to-balled-up-fists-wisco.html {19 February 2011}.

The history of the use of technically viable wind generators has a much longer past than is suggested in the literature that takes as its point of departure the energy crisis of the early 1970s. This history is thus not restricted to the attempts to construct gigantic wind power plants that were meant to supply an extended, large-scale and long-distance transmission network, but also includes the individually owned wind generators of the inter-war years, as well as cases of communal uses of wind power in Europe.

The self-regulation of wind energy arrangements, in particular, uncovers different social organizations, different modes of energy production and also different conceptualizations of the environment. The automatic windmills did not pollute the environment with exhaust gases, as steam, gasoline and internal combustion engines had done. In the case of the latter, the environment was conceptualized as an infinite reservoir for all kinds of exhaust fumes. There was also a difference in the way they broke down, by killing or not people, as this is exemplified by the history of steam boiler explosions that kept occurring during industrialization.

The small and tremendously successful individually owned wind generators of the inter-war period were the exact opposite of the failed gigantic-scale wind-power plants of the post-war period. In respect to the technicalities of self-regulation, this difference is exemplified by the long-distance high-power lines and alternating current transmission networks of the post-war period as opposed to the low-power, short-distance lines of direct current wind generators. Supply lines of a few metres length in the case of individual units, versus kilometres of power lines in the case of the post-war wind plants. This also brought in its wake land clearance, gate towers, cancerous radiation, noise, high-cost regulation, transmission and maintenance, even a much debated difference as to the aesthetics of the individual low-noise unit as opposed to the high-noise large-scale unit (Tympas 2009; 2011). In geographic terms, the same difference manifests itself as a severe antagonism between urban areas and the rural countryside. The high prices of electricity during the Great Depression did not support rural populations, but forced them, especially the women, to seek work in the cities in order to contribute income for the new high-cost way of life (Righter 1996, 111).

Sustainability from this perspective is ultimately associated with ownership and the mode of energy production. Let me conclude with one of the many contemporary examples of resistance to wind farms from our own times of economic crisis, by quoting a public comment to the Public Service Commission written by the owner of a farmhouse in Cambria, Wisconsin, who was forced to leave his property while a wind farm was being built close to his farm:

> If you believe wind turbines are a good fit for a farm operation, a free source of clean energy, and a benefit to your community, I invite you to come to the Glacier Hills Project and witness the total devastation occurring during construction. Seeing firsthand what is happening here would turn any responsible landowner's stomach. Heavy rains have created erosion that will take years to repair. The number of huge construction equipment and trucks burning fuel is staggering. Good productive farmland is being ripped apart, and will never be the same. The level of disgust is even affecting the most loyal supporters of this project. Hatred of this project is growing worse as each day passes, and we will be forced to live with this for the rest of our lives, all because a few irresponsible landowners, myself included, were taken in by wind developers lies. All this for chump change.[2]

Notes

1 See http://www.wincharger.com/jacobs/index.htm [19 February 2011].

2 Public comment by Gary Steinich, at http://betterplan.squarespace.com/todays-special/2010/7/26/72610-triple-feature-from-open-arms-to-balled-up-fists-wisco.html [19 February 2011].

References

Baker, Lindsay T. (1985), *A Field Guide to American Windmills*, Norman: University of Oklahoma Press.

Baker, Lindsay T. (2007), *American Windmills: An Album of Historic Photographs*, Norman: University of Oklahoma Press.

Beck, Homer C. (2000), 'Windmill tools', *Vintage Windmills Online Magazine* 1 (1), at http://www.vintagewindmills.com [19 February 2011].

Davids, Karel (1998), 'Successful and failed transitions: A comparison of innovations in windmill-technology in Britain and the Netherlands in the early modern period', *History and Technology: An International Journal* 14 (3): 225–247.

Douglas, Graham and Oglethorpe, Miles (1984), 'A survey of Scottish windpumps', *Industrial Archaeology Review* 7: 74–84.

Douglas, Graham and Oglethorpe, Miles (1986), 'Scottish windpumps and windmills: new information', *Industrial Archaeology Review* 9: 82–86.

Heymann, Matthias (1998), 'Signs of hubris: The shaping of wind technology styles in Germany, Denmark, and the United States, 1940–1990', *Technology and Culture* 39: 641–670.

Heymann, Matthias (2005), *Die Geschichte der Windenergienutzung 1890–1990*, Frankfurt: Campus.

Hughes, Thomas P. (1983), *Networks of Power: Electrification in Western Society, 1880–1930*, Baltimore / London: The Johns Hopkins University Press.

Hunter, Louis C. (1979), *A History of Industrial Power in the United States, 1780–1930: Water Power*, Charlottesville, VA: University Press of Virginia.

Hunter, Louis C. (1985), *A History of Industrial Power in the United States, 1780–1930: Steam Power*, Charlottesville, VA: University Press of Virginia.

Hunter, Louis C. and Lynwood, Bryant (1991), *A History of Industrial Power in the United States, 1780–1930: The Transmission of Power*, Boston: MIT Press.

Mayr, Otto (1986), *Authority, Liberty, & Automatic Machinery in Early Modern Europe*, Baltimore: Johns Hopkins University Press.

Righter, Robert W. (1996), *Wind Energy in America: A History*, Norman: University of Oklahoma Press.

Sagrillo, Mick (1992), 'How it all began', *Home Power* 27, at http://www.wincharger.com/wincostory/index.htm [19 February 2011].

Tympas, Aristotle (2009), 'The hubris of the wind turbine', *Anagnoseis*, Avgi news paper 25/1/2009 at http://www.avgi.gr/NavigateActiongo.action?articleID=430556 (In Greek) [19 February 2011].

Tympas, Aristotle (2011), 'From movements to wires', *Anagnoseis*, Avgi newspaper 20/2/2011 at http://www.avgi.gr/ArticleActionshow.action?articleID=599973 (In Greek) [20 February 2011].

White, Lynn, Jr. (1964), *Medieval Technology and Social Change*, London: Oxford University Press.