White Paper

Wind energy in Switzerland: its role and potential

The Power of Energy

axpo

Wind energy in Switzerland – opportunities and responsibilities

As a reliable source of electricity in the winter, wind makes a vital contribution to the stability of our energy system. Countries such as France and Germany might have more high-wind areas to exploit. But in Switzerland, the potential to harness wind energy is significant. We need to ask ourselves, therefore, how the best possible use can be made of our own wind resources. If we look to Austria as an example, we can see that considerable investments have already been made to expand wind energy, with annual production now exceeding 7 terawatt hours (TWh). This clearly shows that Switzerland could also greatly increase its wind energy capacity if we start to exploit the existing potential.

A study conducted by the Swiss Federal Office of Energy in 2022 concluded that, in theory, Switzerland has a wind energy potential of 29.5 TWh a year. Even if we were to begin by concentrating on just one third of this as yet unrealised capacity, we could produce almost 10 TWh of electricity a year, 60 per cent of which would be generated during the winter – a major step up from the current level of just 0.2 TWh. To put this into context, 10 TWh a year is equivalent to almost the entire electricity production of Leibstadt, Switzerland's largest nuclear power plant.

Bearing these facts in mind, surely now is the time to move on from discussing the limits of what is possible to focus instead on how we can harness this enormous potential responsibly. Such decisions should not lie solely with government nor, indeed, with energy companies. All of us must play our part. The aim should not be to compete with the 'heavy hitters', those countries producing the most wind energy. Instead, we must examine our own needs and responsibilities through the lens of sound judgement, for the good of the climate, for future generations, and for the security of our energy supply.

Just as importantly, the reliable supply of low-cost electricity during the winter is crucial to the mitigation of financial uncertainties at every level of our economy, from small businesses to major corporations. Wind energy is without doubt an important part of the solution to that challenge. We must pursue it with purpose and determination.

Executive summary

Wind power is a vital element of the transition to green energy and a sustainable future. It already accounts for a significant proportion of electricity production in Europe, averaging around 20 per cent, while wind power in Germany exceeded 30 per cent of total production in 2024. However, the amount of energy generated from wind in Switzerland is still low, despite the country's significant potential. The aim is to replace the energy generated by nuclear power plants with electricity from renewable sources by 2050. To achieve the net zero target, however, we will also need to replace large numbers of oil heaters with heat pumps and switch from internal combustion engines to electric drive systems in our transportation. All of this means that by 2050 Switzerland needs to generate almost as much additional energy as the amount currently consumed in a single year. To make that possible, we need to harness the potential of renewable energies, both for ourselves and the generations to come.

Wind energy is winter energy. Wind turbines produce around 60 per cent of their energy in the winter, when we need electricity the most and depend heavily on imported electricity. Wind energy also has the big advantage of complementing solar power, which mainly generates electricity during the day and the summer months. Furthermore, the geographical distribution of wind turbines can enhance the stability of the entire energy system. Technological advances have significantly improved the economy and efficiency of wind turbines, making wind energy an increasingly cost-effective source of sustainable electricity. Modern wind turbines are optimised to adapt to varying wind conditions. And, thanks to improved materials, higher towers and larger diameter rotor blades, they are more efficient and capable than ever. Wind energy's dependence on the weather can be mitigated by technologies such as energy reservoirs (pumped-storage power plants, for instance) and supra-regional power grids. These solutions compensate for fluctuations in wind energy production, helping to ensure that it can be reliably integrated into the wider energy system. To achieve this, the right mix of technologies is essential.

When it comes to getting this balance right, Switzerland is already starting from a very strong position. Wind and solar energy as well as hydropower all complement one another well. With the wind blowing and the sun shining, less water needs to be fed through hydropower turbines and can even be pumped back to replenish the upper reservoir.

Planning and constructing wind power facilities also requires careful consideration of the various interests involved, as well as the regulatory conditions. The transition to green energy and the use of sustainable energy sources such as wind represent a major opportunity for Switzerland. They can help meet our climate targets and enable us to build a sustainable, resilient and cost-effective energy system. Almost every technology has some kind of impact on the landscape and is visible to some degree. Wind turbines should come to be regarded as an essential part of a modern landscape, just like electricity pylons or reservoirs with their dam walls.

Axpo is committed to helping create a secure, low-emission supply of energy for Switzerland through wind energy projects. To this end, we are looking for sites where wind farms would be both economically feasible and environmentally sustainable. Axpo remains committed to developing innovative solutions to these challenges, helping shape the future of energy and leading Switzerland towards a more sustainable, secure, and renewable energy system.

Why does Axpo want to expand wind energy in Switzerland?

Wind energy's huge potential

Switzerland faces the significant challenge of needing to generate an additional 50 TWh of electricity a year from low-emission sources by 2050.[1] Under legislation currently in force, the country's nuclear power plants are to be decommissioned. Yet the demand for electricity continues to grow as decarbonisation drives an increase in electrically powered transportation – so-called electro-mobility – heat pumps grow in popularity, and the demand for computing power continues to rise exponentially.

As things stand, there are currently only 47 wind turbines in the whole of Switzerland. CKW, a subsidiary of Axpo, operates one of these. Axpo believes there is enormous potential for wind energy in Switzerland. Developing just one third of this could produce approximately 10 TWh of additional electricity by 2050. Some 60 per cent of this extra power would be produced in winter, when demand is currently at its highest and looks set to remain so for the long term. It is imperative that we do not waste this potential.

Wind power is a crucial element of the transition to renewable energies. Only hydropower, solar energy and nuclear power generate similarly low CO_2 emissions.[2] A wind farm produces 45 times more energy than it takes to construct it. Today, only 0.2 TWh of electricity is generated by wind energy in Switzerland, equivalent to around 0.3 per cent of the country's electricity demand. In Europe, wind energy already accounts for 545 TWh a year (approximately 20 per cent) of the total electricity generated, some 446 TWh of which is produced by onshore wind farms.[3]

Key contribution to security of supply

Although wind energy cannot be controlled, it can be readily predicted, right down to the hour. On the markets, energy is traded in quarter-hourly segments, meaning electricity from wind power can be deployed efficiently. The ability to plan wind energy allows it to be integrated into a broad portfolio that also includes solar energy, hydropower and nuclear energy, meaning demand can be generated at all times. Wind energy plays a key role in the winter months especially, when the sun is shining less brightly and the rivers are carrying less water. During these months, wind energy helps to reduce the rate at which reservoirs are emptied. All of this shows just why wind energy is so crucial to our security of supply in the future, a security which is essential if Switzerland's economy is to remain internationally competitive. Constant and reliable energy must be available every single second of the day. Wind energy can play a vital role in making it so.

- **Seasonal production patterns:** the availability of wind energy is highly seasonal. Fortunately, during the winter when energy demand is highest, the average wind speed also increases, while cooler temperatures make the air denser, helping the turbines extract more energy from the wind. Some 60 per cent of annual wind production occurs during this period.

- **A partner for solar energy:** wind and solar energy complement each other perfectly. Solar power plants are at their most productive during the day and in summer, while wind turbines often generate more energy overnight and during the winter. This combination results in a balanced and reliable supply of energy from renewable sources. Since more wind energy is available in the winter than solar energy, a larger proportion of wind energy is required to balance out production over the course of the year.

[1] Source: Axpo Power Switcher (2024).
[2] Source: Axpo Power Switcher (2024).
[3] Source: Windeurope.org, figures refer to 2023, EU27 + UK.

- **Geographic distribution and easy dismantling:** wind turbines can be distributed over a large area, resulting in well-balanced production. This geographical diversification stabilises the system as a whole. Furthermore, at the end of their service life wind turbines can be completely dismantled quickly and easily, unlike water storage power plants or nuclear power facilities, for example.

Renewable energies by their very nature are dependent on changeable weather conditions, a situation which poses particular challenges. A variety of strategies are used to overcome this:

- **Supra-regional and smart power grids and market mechanisms:** constructing power grids across more than one region and establishing flexible market mechanisms make it possible to better distribute energy to where it is needed. Smart grid technology also helps to balance supply and demand in real time.

- **Energy reservoirs:** storing excess energy and releasing it when needed compensates for fluctuations in supply. Pumped-storage power plants, battery storage systems and even potential hydrogen production have important roles to play here.

If Switzerland is to close the gap in electricity demand by 2050, we will need to expand our energy infrastructure. Inevitably, this will change the landscape. And, just like any other infrastructure project, wind turbines will impact the way our landscape looks. This will, of course, require a change in perspective, an acceptance of a more modern vision of the environment around us that includes wind turbines and solar plants. Because if we fail to grow our infrastructure there is a real risk in the long term of becoming overly dependent on energy imports or running into power shortages. The federal government also took this view in the national risk analysis it conducted four years ago, stating that power shortages pose the greatest single risk to Switzerland.[4] The stark truth is, sitting back and waiting for something else to come along is simply not an option.

[4] The national risk analysis identified the three greatest risks as – in descending order – sustained power shortages in winter; a flu pandemic; and the mobile communications network going down. All three of these pose a high level of risk, in other words high potential for damage coupled with a relatively high likelihood of occurrence. Source: Federal Office for Civil Protection FOCP, "Disasters and Emergencies Switzerland" (2020).

What are the financial and planning aspects of wind energy?

Involving local people in the creation of value

Every wind project is ultimately a local one, bringing benefits to its locality, including financial ones. Axpo encourages communities, if they wish, to participate in their local operating companies. Wind turbines also bring economic advantages in the form of remuneration and tax revenue, while landowners receive rent.

Local people can benefit from the value offered by wind turbines in a variety of way, such as:

- Financially through, for example, fixed base remuneration, plus a variable component depending on the annual return; and/or remuneration for building rights.
- Public and financial participation through community investment schemes
- Funding of local community projects
- Associated benefits
- Taxes and other financial receipts
- Sponsorships

Wherever possible, Axpo also seeks to create value at the regional level by ordering materials and services from local suppliers. Thus, in various ways, the development of a wind power facility can bring significant benefits to a community.

Planning rules for wind farms

Planning a wind farm is a detailed and meticulous process, involving numerous considerations. Before anything else can go ahead, a cantonal structural plan is required. Suitable locations for the project must then be identified, which involves balancing a range of different local interests. Once a potential site has been identified, the potential and feasibility of the project must then be confirmed. This involves a number of factors, including initial estimates for the grid connection, transportation, building regulations, and ground suitability. Wind energy evaluations (including recorded data) are critical, as they provide an indication of the cost-effectiveness of a wind turbine installation as well as the underlying data needed to select a suitable type of system.

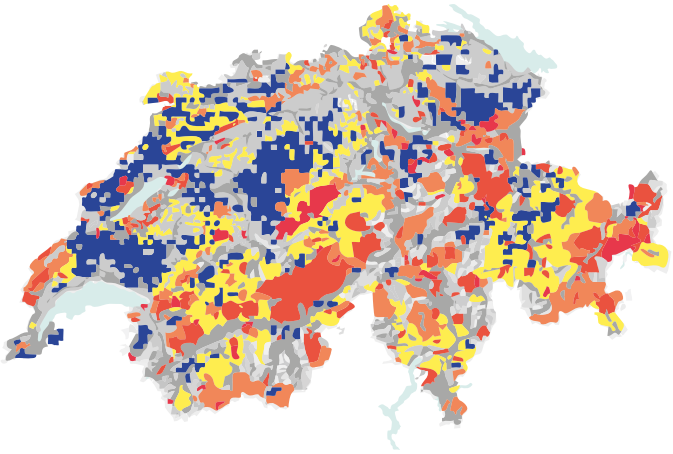

Figure 1: Wind potential ● High potential 125 m above-ground and federal government interests ● Construction zones with buffers (noise protection) ● Protected areas without balancing interests ● Areas generally excluded ● Restricted areas (not exhaustive). Source: SFOE[5].

Once these initial factors have been clarified, a comprehensive environmental impact assessment (EIA) must be undertaken. This is a central part of the numerous investigations that are legally required before a planning application can be submitted. According to Article 10a of Switzerland's Environmental Protection Act, an EIA must be undertaken for wind farms with an installed capacity of more than 5 megawatts (MW). An EIA, which covers more than 20 different areas, ensures that wind turbines can coexist in harmony with nature and society. Project developers and the relevant authorities must examine whether the proposed construction and operation comply with applicable laws, and determine the measures needed to construct and operate the facility in an environmentally sustainable and cost-effective manner. The next stage is the permitting process for land-use and construction, which is conducted in accordance with the regulations of the canton in which the proposed project will be located.

[5] Source: https://www.uvek-gis.admin.ch/BFE/storymaps/EE_Windatlas/?lang=en

Opponents also have the right to object to an authority's decisions; indeed, such opinions need to be anticipated and addressed. In Switzerland, the regulatory conditions for wind energy developments are governed by various federal and cantonal offices, as well as the Energy Act. When planning wind farms, aspects pertaining to energy supply, noise, nature and landscape protection, civil aviation and national defence must also be considered. Cantons need to define suitable areas for wind energy in their structural plans. These conditions highlight the complexity of the regulatory requirements and planning processes for wind energy projects in Switzerland, which require various interests and technical requirements to be carefully considered.

A wind farm is deemed to be of 'national interest' if it produces more than 20 gigawatt hours (GWh) a year, roughly equivalent to the electricity consumption of 4,400 households. Two to three modern wind turbines are required to produce this amount of power. Under the new law on electricity supply, energy production takes priority over other interests in such cases.[6]

[6] Article 9 (4) (c) of the Electricity Supply Act (from 1 January 2025): wind parks of national significance in suitable areas defined by cantons take priority over other interests.

How much does a wind turbine cost?

The sum invested depends on how effectively the project is designed. For wind turbines with a capacity of 4 to 6 MW, we estimate costs of CHF 8 to 12 million, including grid connection and project planning costs. This figure might increase significantly, for example, due to poor accessibility to a remote location or its distance from the grid connection point. However, it can be assumed that these costs are likely to decrease as the number of turbines installed increases, since lessons learned can be integrated into the existing plan. All in all, such economies of scale coupled with technological progress have resulted in wind energy becoming one of the most cost-effective ways of generating electricity. The economic efficiency of a turbine depends not only on costs but electricity prices, too. The higher the average electricity price achieved by a system, the greater its value. In this regard, wind turbines tend to have a greater value than photovoltaic systems, since a wind turbine can also generate electricity during the night and in cloudy weather.

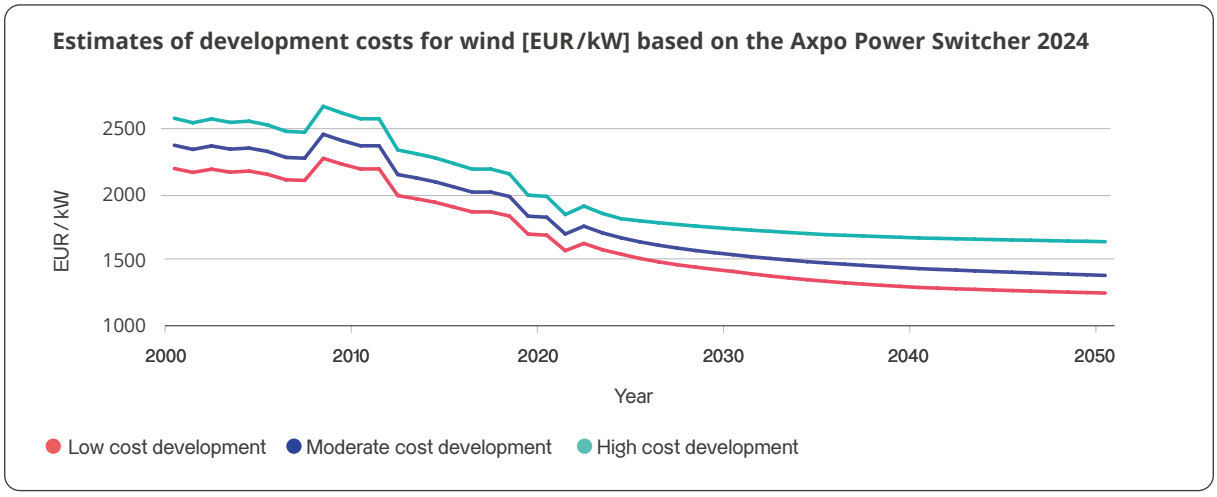

Figure 2: for wind, the average costs per kW of installed capacity have decreased significantly in Germany over recent decades. Data: 2024 real values, 1990–2023 historical data for Germany (converted to CH pricing level), 2024–2050 expected development in Switzerland. Source: Axpo Power Switcher.

What are the technological aspects of wind energy?

Generally speaking, wind turbines are designed to operate for 25 to 30 years. Such longevity makes them projects that span generations, guaranteeing a secure and sustainable electricity supply not just for us but our children, too. When a wind farm is decommissioned, the wind turbines and their towers are fully dismantled – including the foundations.

Why build one large turbine rather than lots of small ones?

Large wind turbines produce proportionally more energy than small ones, as the following calculation shows. **E**, the energy produced by a wind turbine, is calculated from the power **P** and the time **t**:

$$E = P * t$$

P depends on the swept rotor area **A** and the wind speed **v**. In general, large turbines are preferred because they have a larger swept rotor area and can make use of higher wind speeds. They are also more efficient when it comes to construction, operation and use of resources.

If it were just the swept rotor area that determined the energy generated by a turbine, doubling the rotor length would result in four times as much energy being produced, because the area of a circle is a function of the radius squared. However, there are several other factors that also play a role in determining the energy generated by a turbine, as the formula below demonstrates:

$$P = \frac{1}{2} * \rho * A * v^3 * C_p$$

Where:

- **P** is the power (in watts),
- **ρ** is the air density (in kilogrammes per cubic metre, kg/m³). The standard air density at sea level is approximately 1.225 kg/m³
- **A** is the swept rotor area, in other words the area covered by the rotor blades (in square metres, m²). This can be calculated as $A = \pi * r^2$, where **r** is the radius of the rotor blade
- **v** is the wind speed (in metres per second, m/s)
- C_p is the coefficient of power, a dimensionless number that describes how efficiently the turbine converts wind energy into mechanical energy. The maximum theoretical value of C_p is 0.593 (Betz's law), but real turbines typically have a value of between 0.3 and 0.5.

This formula demonstrates that, with all other factors remaining the same, wind speed is the decisive factor for performance. Doubling the wind speed, for example, results in an eightfold increase in power. A longer rotor length also means that the turbine hub is positioned higher. As the height increases, so does the average wind speed. At greater heights, the wind is also less affected by eddies than closer to the ground. Accordingly, doubling the rotor length increases the power by much more than the square. However, the influence of air density **ρ** must also be considered. While wind speeds tend to be higher in the mountains, the air density is lower, which somewhat counteracts the effect of altitude on wind speed. There are also much greater construction and logistical challenges in mountain locations.

To illustrate the problem, let's look at an extreme example: here we compare the power of a small wind turbine with a rotor radius of 1.5 metres, installed on a roof 15 metres high, with that of a large turbine with a rotor radius of 60 metres and a hub height of 140 metres. Let's also assume that the average wind speed at the hub height of the large turbine is 85 per cent higher than at the smaller turbine.[7]

[7] Source: https://wind-data.ch/tools/profile.php?lng=en, assuming a roughness class of 1 for the terrain.

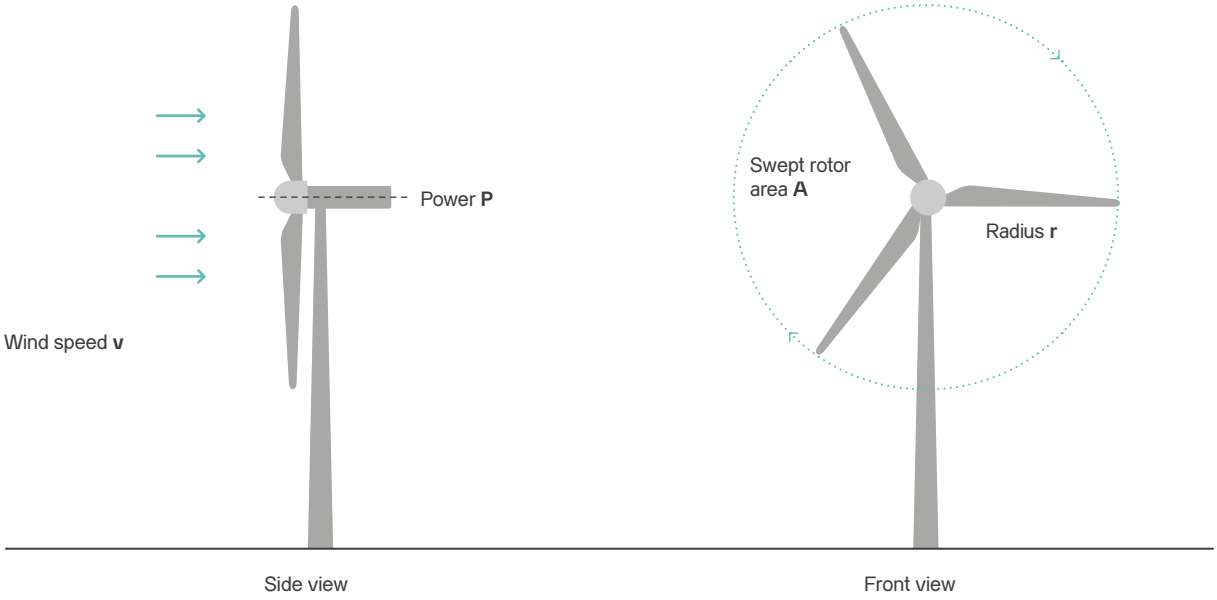

Figure 3: simplified illustration of a wind turbine with rotor blade radius r, swept rotor area A, wind speed v and turbine power P.

Rotor blades 2x as large > 4x more wind energy

+ higher hub height and thus greater average wind speeds

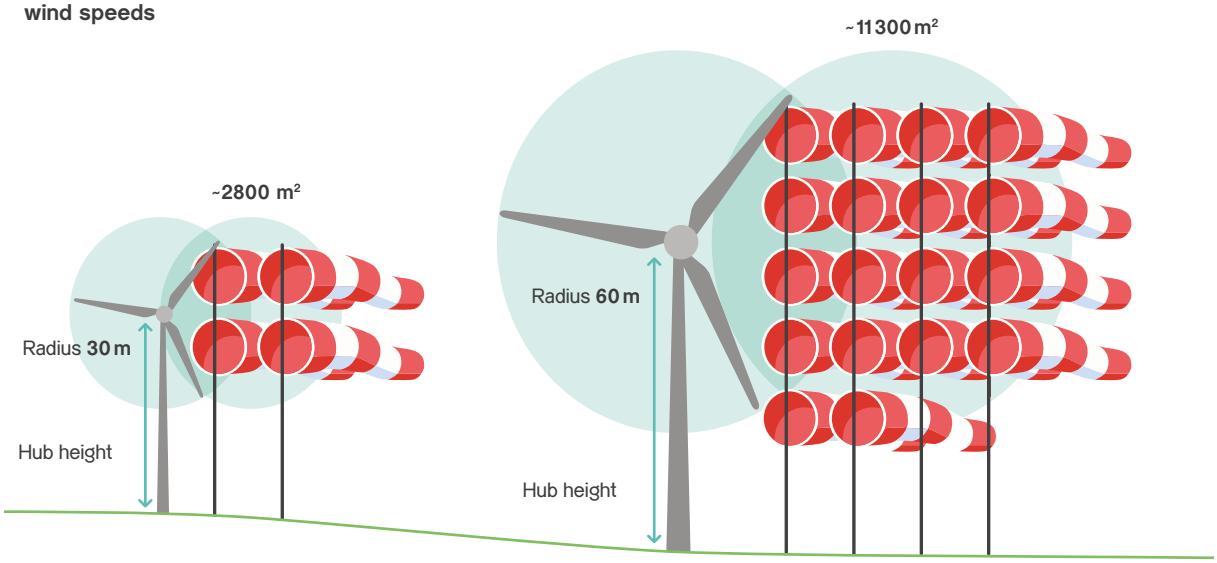

Figure 4: a turbine with rotor blades that are twice as large produces four times as much wind energy, purely based on the larger swept rotor area. And with the wind being stronger the higher the hub is positioned, the energy generation factor increases even more.

Although the swept rotor area of the large turbine is only around 1,600 times larger, roughly 10,000 small turbines would be needed to generate the same amount of electricity.

New turbines are on average larger than older ones since modern materials and production processes have made it possible to scale up. In Spain, for example, a repowered wind farm now generates 30 per cent more electricity, despite having four times fewer turbines than before.[8]

How do modern wind turbines differ from earlier models?

Switzerland is less windy than many European countries. However, modern wind turbines can generate electricity effectively thanks to the immense progress that has been made in wind technology. In the past, a wind speed of 7 m/s was needed to produce electricity efficiently. Nowadays, 5 m/s is sufficient. Modern wind turbines begin to produce energy at just 3 m/s and are around 12 times more efficient than they were 25 to 30 years ago.[9] Compared to earlier models, modern wind turbines feature numerous improvements:

- **Higher, longer, more powerful:** stronger and more lightweight materials make it possible to build higher towers and longer rotor blades. This means the wind can be harnessed more efficiently to generate power from the faster and more constant winds found at greater heights. Nowadays, modern onshore turbines achieve 5 to 7 MW, more than double the value of 2 MW reached by older turbines at the same location.
- **Adaptable turbines harness the wind:** modern wind turbines can be optimised to make more effective use of a site's specific wind conditions, maximising the energy yield. Different rotor blade designs and control systems enable efficient operation at low and high wind speeds.
- **Improved control and monitoring:** advances in sensor systems and data processing have paved the way for more precise control and monitoring of wind turbines. This increases both efficiency and lifespan, since problems can be detected and resolved at an earlier stage.
- **Lower noise emissions:** these technological developments have also enabled the installation of various noise modes on wind turbines, ensuring that they always stay within the required noise limits.

[8] Source: Iberdrola (2024); https://www.iberdrolaespana.com/about-us/business-lines/onshore-wind-energy/repowering-wind-farms-spain

[9] Source: Suisse Eole (2024); https://suisse-eole.ch/de/blog/eine-erprobte-technologie/

Axpo: a trusted partner in local wind energy

In Switzerland, famed for its commitment to precision and sustainability, Axpo is helping guide the way to a greener future. As a leading operator of renewable energy sources, in particular hydropower, Axpo has always placed efficiency and innovation at the forefront of its activities. Now we are expanding our horizons by aiming to bring the same excellence and innovative drive to wind energy.

However, implementing wind energy projects comes with a whole host of challenges, from responding to objections to coordinating construction and navigating the regulatory landscape. We want local communities and businesses to be closely involved throughout the entire development process. To do so, we aim to promote dialogue and work together to find solutions that meet both social and environmental demands.

Axpo is determined to help create a secure, low-emission energy supply for Switzerland through wind energy projects. Doing so demonstrates our continuing commitment to a future in which renewable sources form the backbone of our energy supply system. That is why we are investing in new projects in Switzerand. And why we are seeking locations where wind farms will be economically feasible, environmentally sound, and socially acceptable.

Axpo has been engaged in successful partnerships with local communities for decades, including those places where hydropower plants are operated. We can say with confidence that Axpo has proved itself to be a competent, action-focused and reliable partner. Together we can help drive forward the green energy revolution and ensure that Switzerland maintains its position as a pioneer of safe, sustainable and low-emission energy.

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