# The Smartest, Greenest Grid

## What the little Danish island of Bornholm is showing the world about the future of energy

By Jean Kumagai
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Photo: Nicky Bonne

Europe's Future Grid

**On Christmas night,** Maja Bendtsen and her husband were curled up on the couch watching TV in their cozy house on the Danish island of Bornholm. Suddenly the house lost power. “The lights flickered briefly and then everything went black,” Bendtsen recalls.

Peeking out the window, they saw that the whole neighborhood was dark. A few quick phone calls confirmed that all of Bornholm was without power. Bendtsen, an engineer with the island’s utility, Østkraft Net, mentally ruled out the obvious culprits: It wasn’t a particularly busy night, as Christmas festivities had wrapped up with the midday meal, nor was the weather particularly cold or stormy.

She thought of one thing, though, and it made her heart sink. She phoned the Østkraft control room, where the chief engineer confirmed her suspicion: A ship dragging its anchor in the

narrow Baltic Sea channel between Bornholm and Sweden had severed the 60-kilovolt, 70-megawatt undersea power cable that is the island's only external source of electricity. It would take a repair crew more than six weeks to pinpoint the damage, haul the cable to the water's surface, and fix it.

Incredibly, this was the fourth such mishap in 10 years. "We're getting accustomed to it, almost," Bendtsen says. By "accustomed" she doesn't mean "resigned." During the last decade, Østkraft has built up an impressive array of renewable sources [PDF] like wind, solar, and biomass, which can now supply about three-quarters of the island's demand. In the process, Bornholm has transformed itself into a kind of living laboratory for testing new energy ideas.

Now it is taking the ultimate step, by deploying one of the world's most advanced smart grids, called the EcoGrid EU. It's a four-year, €21 million (US $27 million) project, funded in part by the European Union, that aims to demonstrate how electricity will be produced, distributed, and consumed in the future. While any smart grid today can track in excruciating detail electricity supply, demand, and other information, Bornholm's is one of the first in which individual household consumption can respond to real-time price changes in the electricity market. By doing that, the grid's customers are helping to balance the sometimes big and sudden swings in supply that inevitably accompany the use of wind and solar power.

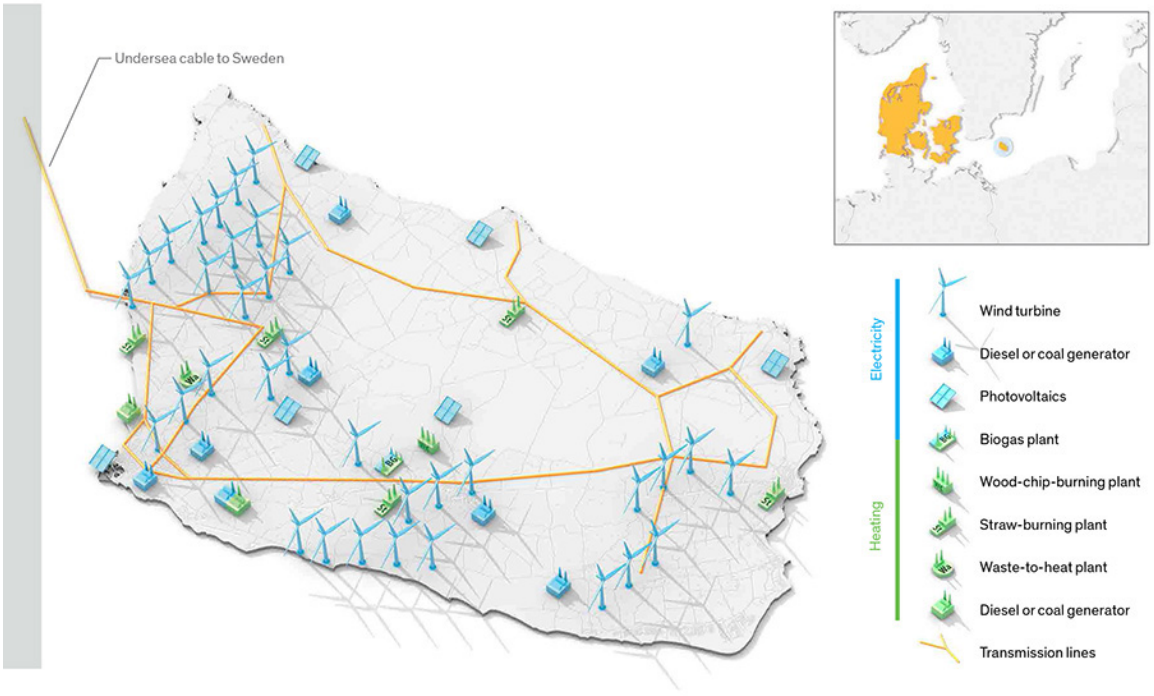


Illustration: Bryan Christie Design **Green Grid:** The Danish island of Bornholm has only 41 000 full-time residents, but it now boasts one of the world's most advanced smart grids, which should help optimize the operation of its diverse mix of energy sources, including wind, solar, and biomass, as well as traditional coal and diesel.

And as Bornholm goes, so goes Denmark and the rest of Europe. The European Commission's 20/20/20 Plan, for instance, states that by the year 2020, greenhouse gas emissions will be cut by 20 percent, while renewable energy usage and energy efficiency will both rise by 20 percent. Last year, the Danish parliament approved an even more ambitious target: to have renewables supply 35 percent of the country's total energy needs—not just electricity but also heating and transportation—by 2020, and an incredible 100 percent by 2050. Can those targets actually be reached?

Photo: Nicky Bonne **Lost at Sea:** Bornholm's only link to the Nordic grid is via a three-phase undersea cable, which has broken four times in the last 10 years.

That's what the EcoGrid project aims to find out. The choice of Bornholm, with its 41 000 full-time residents, to host it was no accident. Although the island's beauty draws hundreds of thousands of tourists every year, it's not just a vacation destination. Commercial fishing, dairy farming, and arts and crafts all buttress the economy and give Østkraft a representative mixture of commercial, industrial, and residential customers, as well as schools, a hospital, an airport, and an international seaport.

"We're like a microcosm of Danish society," Bendtsen says. "We are in many senses a picture of the future power system in Denmark." And by studying how a high-tech grid can help this little island cope with the challenges of renewable energy, EcoGrid's organizers hope to discover larger lessons for the wider world.

**Bornholm has long** held a special place in the Danish psyche. According to local legend, when God got to the end of his creation he still had bits of paradise left over, and so he threw them all down in the Baltic Sea and created Bornholm. In medieval times, another tale goes, Danish kings hid their mistresses away in the island's large forest. Today, Europeans flock to Bornholm in the summer for its beautiful sandy beaches, sunny (for Denmark) weather, and, yes, that forest.

Photo: Technical University of Denmark (DTU) **Island Oversight:** Researchers at the Technical University of Denmark, outside Copenhagen, can monitor Bornholm's power grid in real time.

For Jacob Østergaard, though, the most attractive thing about Bornholm isn't the beaches or the sun: It's that pesky undersea cable, or, more important, what that cable allows him as a power engineer to do. Østergaard, a professor of electrical engineering at the Technical University of Denmark (DTU), in Lyngby, is involved in a number of electricity projects on Bornholm, including EcoGrid. The cable can be switched off at will, he explains, putting the Bornholm grid into what's known in electricity circles as "island" mode. And that's interesting, he says, because the wealth of wind power makes the Bornholm grid challenging to operate and fascinating to study. Last year, he and his colleagues even built a duplicate of the Østkraft control room on the DTU campus to monitor the Bornholm grid in real time.

On a windy day, Bornholm's turbines can supply up to 30 MW of power, or more than half of the island's peak load of 55 MW. But the wind blows as it will, and that variability and unpredictability can wreak havoc on the grid's stability. If the wind abruptly dies, for instance, electricity supply could dip way below demand, causing the grid's nominal 50-hertz frequency to

likewise plummet. A dip or a spike of just over a tenth of a hertz is cause for alarm, Østergaard says, and if it drifts out of kilter even further—to, say, 47 Hz—it can trigger a blackout.

Something close to that happened on 17 September 2009 [PDF], when the sea cable was shut down for maintenance. To keep the grid balanced, the wind turbines were also initially shut down. At 11:25 a.m., all was calm, with the grid frequency steadily hovering just north of 50 Hz. Then, at 11:26 a.m., six of the turbines were turned on, and over the next several minutes their share of the island's power supply rose to 15 percent.

But as the wind output grew erratic, so did the grid frequency, spiking more than a tenth of a hertz several times and dropping sharply to 49.8 Hz just before noon. Østkraft engineers and DTU researchers were closely monitoring the situation and quickly stepped in, ramping up the output of the island's conventional generators and dialing back the proportion of wind to 10 percent, at which point the frequency returned to normal.

Photo: Nicky Bonne **Fueling the Future:** The main power plant on Bornholm burns wood chips in addition to coal and diesel.

Dozens of experiments before and since have confirmed that there's an upper limit of about 15 percent on the amount of wind power that Bornholm's grid can absorb when in island mode. And to greater or lesser degrees, all power grids that have a substantial amount of wind and solar do the same thing, falling back on traditional "peak" generators to compensate for gaps in renewable output. Some grid operators also store electricity in pumped hydro or compressed-air

installations or in industrial-grade batteries, but the latter aren't yet economical, and the former can be used only in certain locations.

But what if, instead of boosting generation when demand is high, you just cut back demand? Answering that basic question is at the heart of the EcoGrid.

**The goal of the smart grid** isn't to demonstrate that Bornholm can be energy independent, notes Bendtsen, sitting in one of the light-filled offices at Østkraft's sleek headquarters just outside the main town of Rønne. The island is independent already: At present it has about 50 MW of domestic capacity, from a mix of conventional coal and diesel generators, three dozen wind turbines that dot the countryside like giant pinwheels, rooftop photovoltaics, a biogas plant, and several wood-chip- and straw-fired plants. As a result, the Christmas night blackout lasted only a few hours, the time it took to bring the domestic plants online.

But producing electricity that way is expensive, and so the cable to Sweden lets the island buy electricity from the Nordic grid when it's cheap and sell when the price is high. Ordinarily, trading in electricity markets is done at the level of utilities and the like. EcoGrid is letting individual households and smaller businesses also become market players.

The idea is to shift the consumption of electricity to periods of the day and night when electricity demand and prices are low, Bendtsen explains. You could do that by simply sending people a text message whenever prices change. But that would quickly get tiresome.

Photo: Nicky Bonne **From Waste to Watts:** Bornholm's 2-megawatt biogas plant [right] converts manure and other organic waste into electricity and heat.

"And if we let people interact directly with the market, their behavior will, of course, change," says Østergaard. "Everyone will want to charge their electric vehicles when the price is low, for example. If too many people do that, you create congestion in the weakest parts of the grid."

Instead, EcoGrid's people have installed smart grid controllers [PDF] in about 1200 households and a hundred businesses, and since April the controllers have been receiving a continuous stream of data based on the 5-minute price for electricity in the Nordic electricity market, which covers Denmark, Finland, Norway, and Sweden. The controllers wirelessly communicate with

designated appliances, and algorithms determine whether to turn each one on or off, based on factors like the time of day, the weather, and current, past, and future market prices.

At first, the project's organizers envisioned regulating a whole suite of household machines—dishwashers, washing machines, refrigerators, TVs, lights. It turns out, though, that although such smart appliances have been on the market for years, there's still no standard protocol for automating them. So your dishwasher might speak ZigBee while your freezer converses in KNX, and they can't easily understand each other.

Standards clearly would help, says Bendtsen. "Imagine that you go to a white goods store to buy a new dishwasher," she says. "You have to consider not just what size and what color and how much energy and water does it use but which language does it speak. Fine if you're an engineer, but we need some sort of standard so that ordinary people don't have to think about all these things themselves."

In the meantime, the EcoGrid is keeping things simple and dealing primarily with households that have electric heating systems and heat pumps. In 700 of those households, the heating system is directly controlled using algorithms developed at IBM's research lab in Zurich. A thermal model of each household has been created, based on factors like electricity usage patterns and the size of the windows and walls, explains Dieter Gantenbein, smart grid project leader at IBM Research–Zurich.

"If you leave the window open a lot to let your cat in and out, then your parameters will be different from somebody who keeps the windows closed," he says. From the thermal model, he adds, "we can determine the electrical flexibility of this house—we have a planned strategy on how to throttle the heat pump up or down. The goal is that the owners do not see any reduction in their quality of life." About 100 businesses on Bornholm are being similarly equipped.

Photo: Nicky Bonne **Showing the Way:** A demonstration house on Borholm is equipped with rooftop photovoltaics and smart-grid devices to let people see how these technologies work.

Another 500 or so households are being treated as a single electricity- consuming unit; Siemens's Denmark subsidiary is coordinating that part of the smart grid. The remainder of the 1900 households enrolled in the project—about a tenth of the island—are just getting smart meters, which provide them with fine-grained information about their electricity consumption and market prices but don't control their usage in any way.

Interestingly, EcoGrid participants aren't being told to expect a drop in their electricity bills. That's partly a way to manage expectations, but it's also just being realistic: Numerous studies in Denmark and other countries have shown that the incremental savings people get from being more energy efficient usually aren't enough to change their behavior. That said, Gantenbein notes, there's been no lack of volunteers on Bornholm.

"Danes take preservation of the environment close to their hearts," he says. "It's like a sport. They heat carefully, they close doors, they use different technologies, and by being engaged, they are very enthusiastic to participate in such an ambitious pilot."

Photo: Nicky Bonne **Environmental Enthusiast:** Martin Kok-Hansen [left] was one of the first homeowners to sign up for the EcoGrid smart grid. He's already decided to swap his halogen lights for more efficient bulbs.

**Martin Kok-Hansen** is just such an enthusiast. He and his family live in a one-story brick house on the northern edge of Rønne, and he was among the first on Bornholm to sign up for the smart grid. The real estate agent says he decided to participate for the same reason he traded in his Jeep Grand Cherokee for a Volkswagen Golf a few years back. "In the future, we won't have that much power," he says. "And my son is probably going to have kids as well. Where are they going to get all the power from?"

There's now a Landis+Gyr smart meter on the wall of Kok-Hansen's garage, a small relay and reader in the laundry room that turns the electric heater on and off, and a digital thermostat in the living room; all three of these units communicate wirelessly with a "gateway" controller and router that in turn connect via the Internet to the utility company. The gateway and most of the other hardware, as well as the household communication and end-user Web services, were designed by a company called GreenWave Reality, based in Irvine, Calif.

Like other participants, Kok-Hansen can set limits on how warm or cool his house gets. "If it's 21 °C in here and they need the power, they can switch off the heat and let it fall to 18 °C," he says. That's two or three degrees cooler than normal, but he thinks he can cope. "Maybe you put on a sweater for a while."

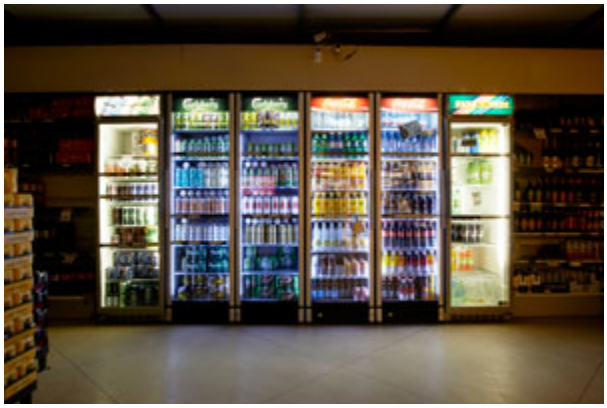

Photo: Nicky Bonne **Smart Beer:** Bornholm has about 200 experimental bottle coolers outfitted with special controllers so that they can respond to changes in grid frequency by automatically turning off or on.

Standing in his recently remodeled kitchen, laptop perched on the black granite countertop, he logs into his account on the Østkraft website. He can see, in near real time, how much electricity he's using. It's been illuminating, to say the least.

"Right now I'm using 1200 watts," he says, pointing to a graph onscreen. "But when you turn this one on"—he walks over to a wall switch and flicks on the recessed halo gen lights overhead—"you see that the usage goes way up." Sure enough, within a few seconds, the graphed value nearly doubles. That's because each halogen bulb is 50 watts, and the kitchen has 16 of them. At current rates, 1 kilowatt-hour runs about 2 Danish kroner, or 35 cents. So keeping those lights on just 4 hours a day is costing him $500 a year, he figures. He plans to swap them out soon for compact fluorescents or LEDs.

"I definitely will change those," he says. "This is a whole new lifestyle."

**The SuperBest supermarket** just off the main square in Rønne is packed on a Saturday afternoon. A young man stops at a refrigerator, pulls out a few bottles of beer, and puts them in his cart. He doesn't bother to read the explanatory sticker plastered across the refrigerator's glass front, nor does he glance up at the shoebox-size device sitting atop the cooler. And so he may have no inkling that this refrigerator, and about 200 other units like it on Bornholm, is special: Like the EcoGrid's heat pumps, the bottle coolers are helping to balance the grid [PDF].

Two years ago, researchers at DTU modified each cooler so that it directly monitors grid frequency, explains Østergaard. In a series of experiments, his group has shown that the coolers can be programmed to turn themselves off when the frequency drops by more than a tenth, and then automatically turn back on when the frequency stabilizes. "If it's just a small frequency variation, then you just have a small number of coolers respond," he explains. "But if there's a large variation, then all of them will react."

The concept of using coolers, pumps, and other appliances in this way has been kicking around for a while, Østergaard says, but only in the last decade or so has it become economically feasible. "These days, every cooler has a thermostat with a microcontroller and processor, so you can just program it to do this," he notes. Whereas the heating systems hooked up to the EcoGrid are reacting to market prices, which are an indirect measure of power supply and demand, the Bornholm bottle coolers are detecting conditions on the grid itself.

Østergaard says both approaches are useful: "It's important to balance the grid on all time scales, from seconds and minutes to days and years." And by using information technology to strategically roll back demand, rather than ramping up supply, the smart grid can create a more efficient network. "Moving bits and bytes is less expensive than moving amperes," he says.

As to whether Denmark and the rest of Europe will meet their lofty energy goals, Østergaard's not saying. "It's good to have goals," he allows. "I don't know if we will succeed. But without projects like this, there is no chance at all."