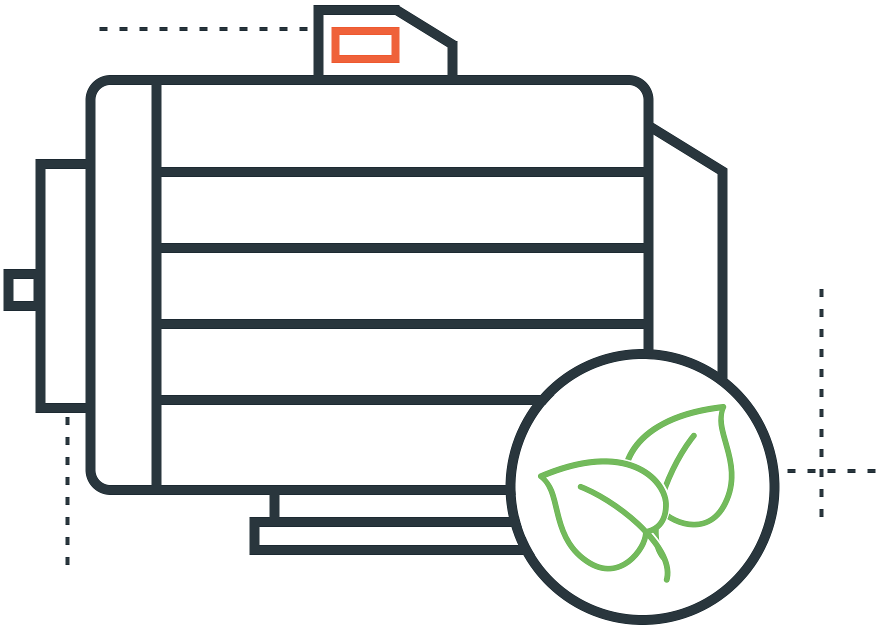
SEMIOTICLABS

WHITE PAPER

Using SAM4 to help drive sustainable industry

SAM4 is a predictive maintenance system that helps maximize asset uptime by detecting developing faults up to five months ahead. But there's another plus: that same data provides concrete insights that enable energy and carbon reductions.



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SAM4 and the ERGO project

SAM4 is a smart condition monitoring system for AC induction motors and rotating assets such as pumps, compressors and conveyors. Six high-frequency sensors measure current and voltage from the safety of the motor control cabinet. SAM4's self-learning artificial intelligence algorithm analyzes the resulting signals to detect equipment faults as soon as they start to develop, and identify the specific failure mode at play. At our installed customer base, SAM4 has detected more than 90 percent of developing faults up to five months in advance, increasing uptime, energy efficiency and overall equipment effectiveness.

Semiotic Labs, the maker of SAM4, has partnered with Nouryon, Vopak, TPA Adviseurs, Vitens, Huntsman and Utrecht University in **ERGO**, a research project led by the Institute for Sustainable Process Technology. ERGO's goal is to develop and validate system-level monitoring features in SAM4 to detect energy inefficiencies and provide data-driven insights to reduce industrial energy consumption by 15–30 percent. Read more about the ERGO project at https://ispt.eu/projects/ergo/.

People, planet, profit: toward greener industry

In November 2019, the International Energy Agency noted that global electricity use is growing at more than double the pace of total energy demand, slating it to overtake oil consumption by 2040. Industrial electric motors are leading that growth. Today, industry is responsible for nearly half of worldwide power consumption.

Much of that energy is inadvertently wasted on motors that are too large for their applications and processes that are not as efficient as they could be. The IEA estimates that adopting best-practice energy performance standards could save 322 terawatt-hours of annual electricity demand and 206 metric tons of CO_2 emissions by 2030, **making electric motor efficiency one of the largest potential sources of greenhouse gas reduction**. That means manufacturers have a golden opportunity to achieve significant carbon and energy reductions, creating a win-win situation that raises both the sustainability of their operations and their bottom line.

To act on that opportunity, companies need hard data that will help them optimize their processes and the motors they use. The good news for companies that use SAM4 to monitor asset health is that the required data is already being collected and analyzed.

Because it measures both current and voltage, SAM4 has the raw data to estimate the efficiency of the motors and processes it monitors. SAM4’s AI software can then operate on that data to extract actionable sustainability insights.

In the pages that follow, we explain how SAM4 estimates efficiency and potential energy savings, then present our results from running that analysis on a representative sample of 303 actual industrial motors. Our discussion here focuses on individual motors, but we also note how these results provide a starting point to inform a company's conversation on process optimization.

Today, industry is responsible for nearly half of worldwide power consumption.

Estimating motor efficiency

To determine how much energy you can save on a motor, you need to know how efficiently the motor is currently operating. You can calculate a motor's efficiency directly, by dividing its mechanical output power by its electrical input power. SAM4 measures electrical input power but not mechanical output power, so we need another way to estimate efficiency.

A motor's efficiency depends on several factors: the motor's size (expressed in kilowatts, or kW), the load on the motor (how hard it has to work, expressed as a percentage), the speed at which the motor rotates (in revolutions per minute, or rpm), and its efficiency class (from lowest, IE1, to highest, IE4). Larger motors are more efficient than smaller ones, as you can see in figure 1.

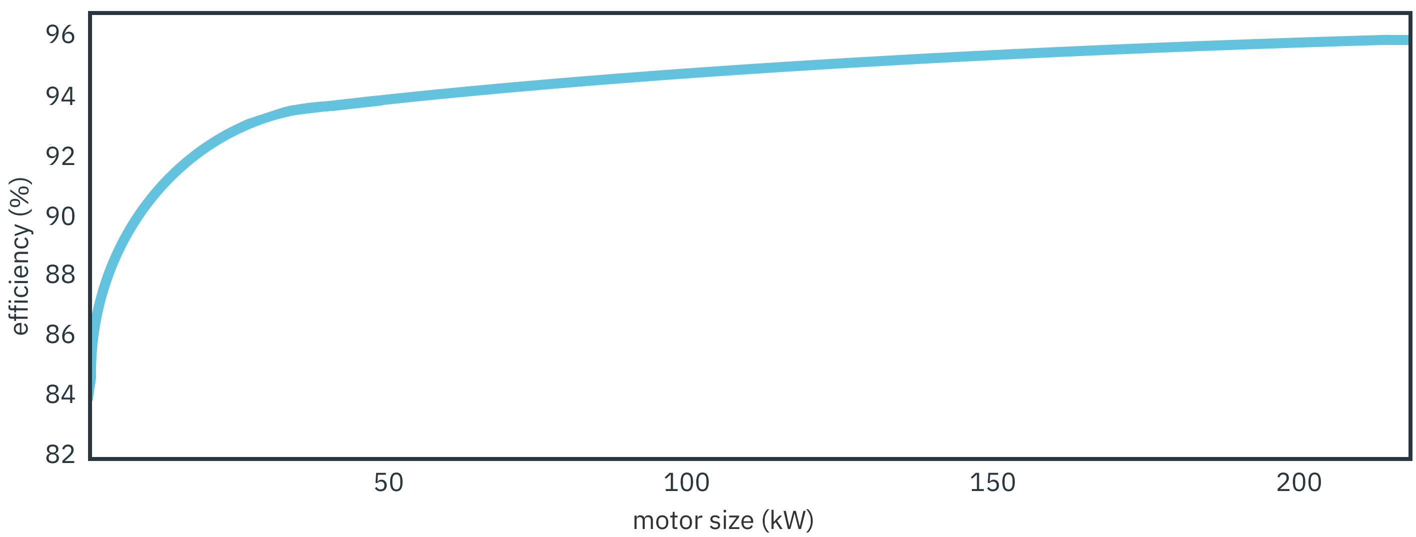


Figure 1. Larger motors are more efficient than smaller ones.

A motor's operational efficiency is the key to calculating how much energy you can save.

The effect of load and speed on efficiency

Motors are also generally more efficient when they run at higher loads and speeds. Figure 2 shows the effect that speed and load have on efficiency for an 11 kW 4-pole IE3 motor driven by a variable frequency drive (VFD).

(For the rest of this paper, we'll be talking about motors that are in the IE3 efficiency class and are driven by a VFD.) This gives us another way to estimate a motor's efficiency, by relating its speed to its load.

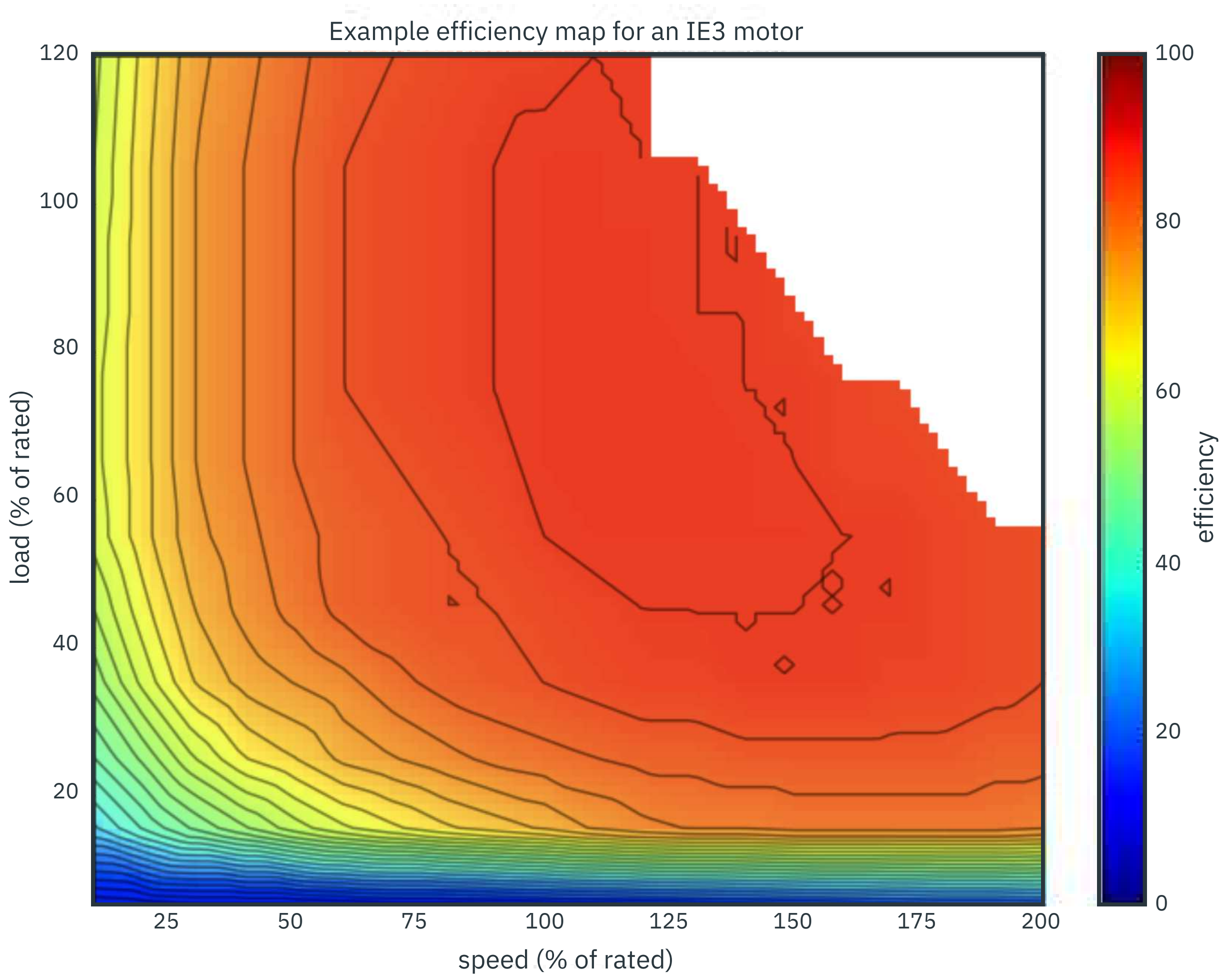


Figure 2. A contour map showing how speed and load affect a motor's efficiency.

Load is related to active power

Now we're in business: SAM4 can extract load and speed from the data it collects. That's because there's a roughly linear relationship between active power (which SAM4 meaures) and load, as shown in figure 3. Specifically, SAM4 measures the current (I) and voltage (V) drawn by the device, then calculates active power (P) using the standard formula P = V * I, taking into account the phase shift between the two.

Speed is related to voltage

Similarly, there's almost always a linear relationship between the voltage a VFD draws (which SAM4 measures) and the frequency it supplies to the motor, as shown in figure 4. Said another way, VFDs will maintain a constant incoming-volts-to-outgoing-hertz ratio for frequencies between 0 and 60 Hz.

Note: Because SAM4 measures both current and voltage, it can actually measure the supply frequency directly. We were not yet tracking that metric for the earliest data in our sample set, so we used the speed/voltage relationship to estimate it for this analysis.

Thanks to these two relationships, SAM4 can use the current and voltage data it collects to reliably estimate load and speed, and thus efficiency.

Load is related to active power, speed is related to voltage

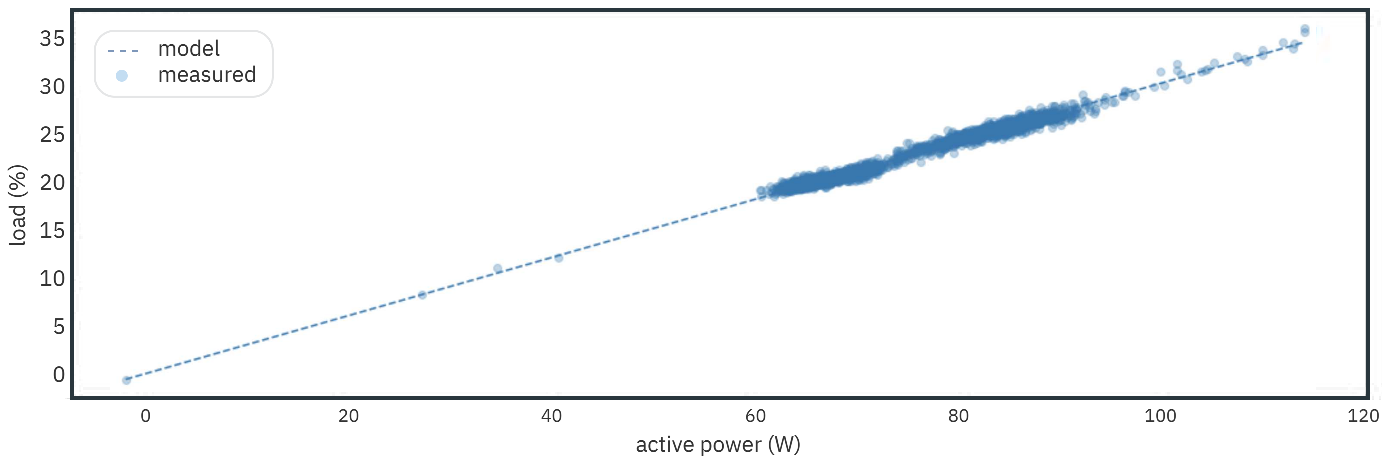


Figure 3. The linear relationship between active power and the load on a motor, taken from actual SAM4 data. Active power is the actual power consumed by the circuit. Electric motors also draw reactive power, which is not converted to actual work. These combine to produce the apparent power: the total amount the power company must supply.

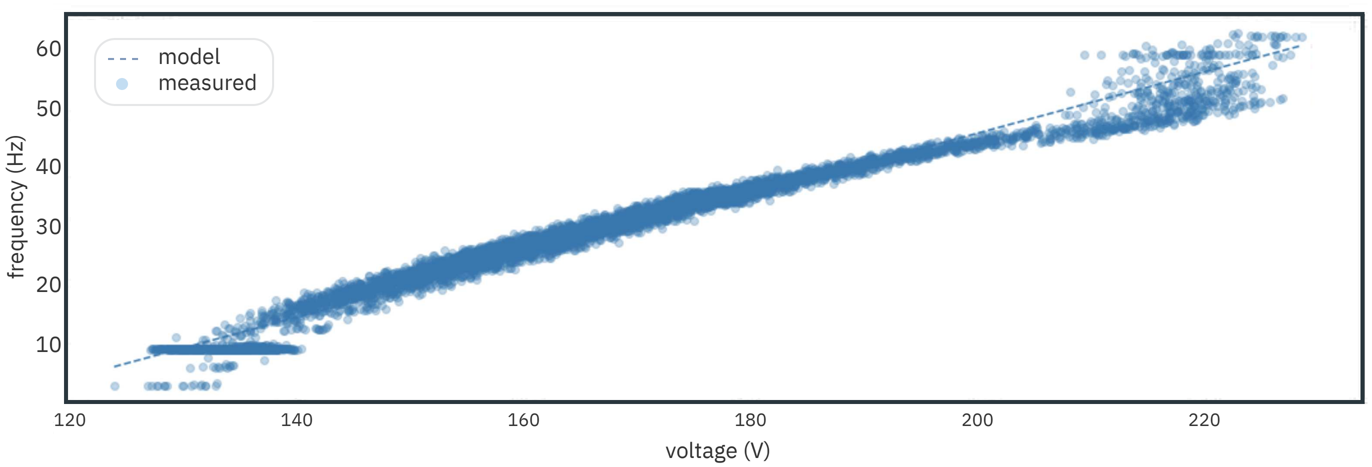


Figure 4. The linear relationship between voltage and frequency in a VFD, taken from actual SAM4 data.

Deducing potential energy savings

SAM4 can inspect all the data it's collected for as long as it's monitored a motor to determine the maximum load that motor must be able to handle (called its *peak load*), which in turn lets it calculate the optimal motor size for the given application (a process called *rightsizing*). By optimal, we mean a motor whose rated (that is, maximum) load equals the required peak load. If there's no real-world motor with exactly the calculated size, we take the smallest motor above that size. (The new, optimal motor and the existing motor are in the same efficiency class (IE3, for our sample set), so that our calculations reflect only those savings related to motor size and not motor design.)

We can then use SAM4's historical data to estimate what the actual load on this optimal motor would have been, and thus its efficiency and energy consumption. The difference between the energy consumed by an optimally sized motor and the energy consumed by the existing motor is the potential savings.

But let's back up a minute. A motor may be efficient at 100 percent load, but if it runs there all the time it will wear out faster. If you're trying to be more sustainable, you need to consider not just the energy the motor wastes during its lifetime, but also the environmental cost of replacing the motor more frequently: the impact from manufacture, transport, disposal and so on. That's a more complex calculation than we're making. So why are we justified in considering only peak load to deduce the potential energy we could save?

The difference between the energy consumed by an optimally sized motor and the energy consumed by the existing motor is the potential savings.

Our approach is justified because we're only looking at motors whose peak load is much greater than their average load. (This is common in industry: consider centrifugal pumps, fans and compressors in inherently variable-load applications. These are precisely the motors that benefit from VFDs, one of the criteria we used in selecting the motors for our sample set.) They need to be *able* to run at that peak load when they have to, but most of the time they'll be running at a lower load. As long as that usual load keeps the motor in the red area of figure 2, the motor will be running at high efficiency with much less wear and tear. The sweet spot is generally 50–80 percent of rated load, with the peak at 75 percent. For these motors, our simplification—downsizing to the smallest motor whose rated load equals the required peak load—can only improve sustainability.

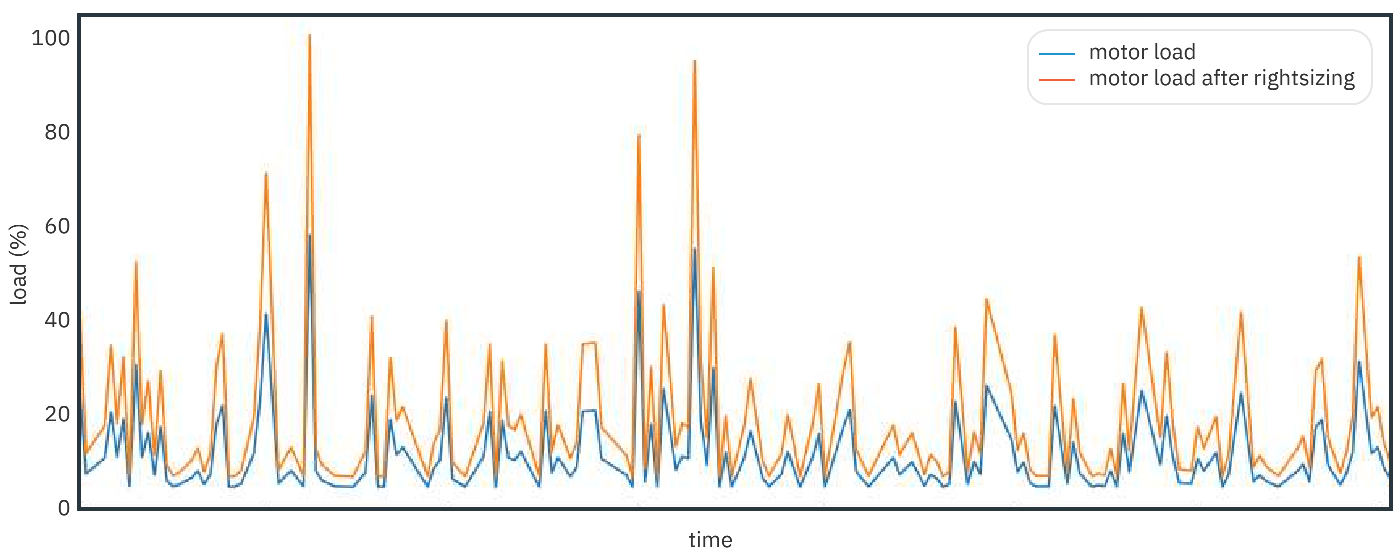


Figure 5. We calculated the potential energy savings for the low-hanging fruit among industrial motors: those whose peak load is significantly higher than their average load. Using a smaller motor saves energy not only through drawing less power by design, but also through raising the average load closer to the efficiency sweet spot.

Results

So how often are motors significantly oversized for their applications—and how much energy can you save when they are? To find out, we ran the numbers on anonymized SAM4 data from 303 industrial motors. We selected these 303 motors as a representative subset of VFD-driven motors across the industries, asset types and applications we monitor. To rule out the influence of motor degradation (a faulty motor generally consumes more energy than a healthy one), our sample set contains only motors without developing faults during the sampled period.

We discovered that more than half these motors could be rightsized to save energy, with savings of up to 53 percent. Rightsizing the 73 least efficient motors in our sample would have cut the total energy bill by more than a fifth. **Rightsizing the single least efficient motor in our sample would save enough energy to power 29 homes per year.**

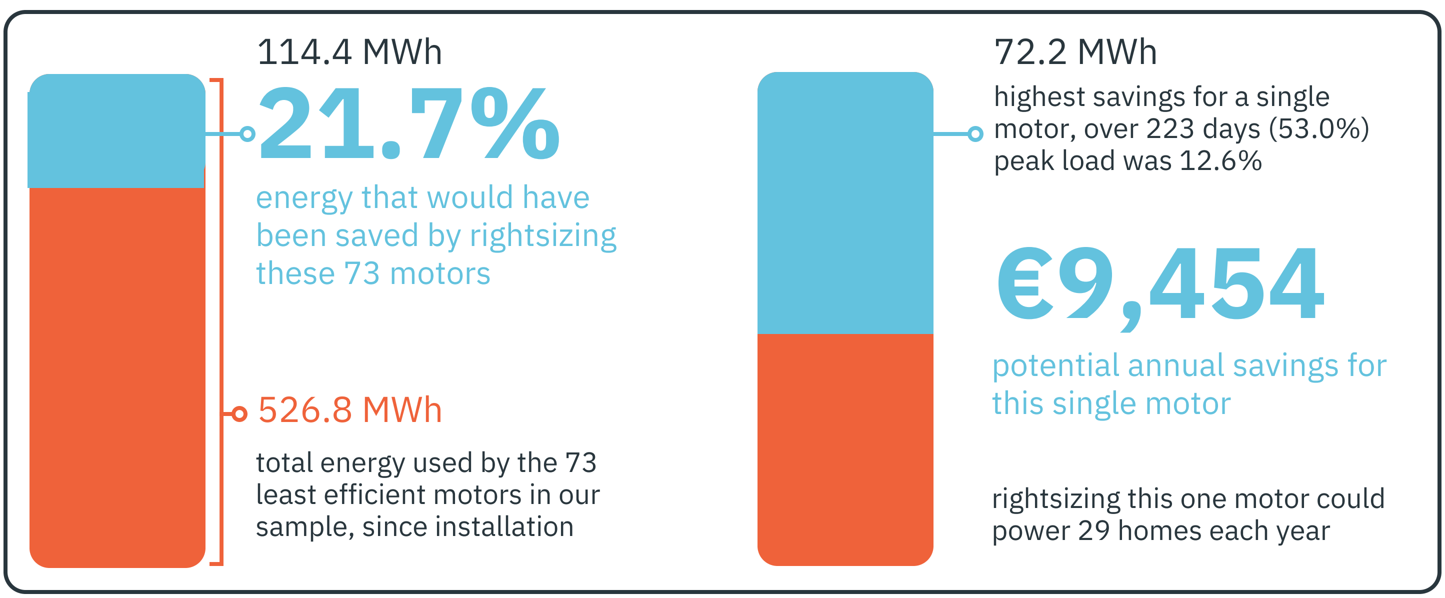


Figure 6. Potential savings in euros were calculated using the median cost of industrial electricity in the EU in 2017. Source: www.enerdata.net/about-us/company-news/energy-prices-and-costs-in-europe.pdf. The equivalent number of homes was calculated using the 2015 EU average. Source: www.odyssee-mure.eu/publications/efficiency-by-sector/households/electricity-consumption-dwelling.html.

SAM4's analysis also revealed that even after rightsizing, the average load on roughly 20 percent of the motors would still be below 40 percent, as shown in figure 7, suggesting there's room to optimize the processes they run in.

(Because we already chose the smallest motor that can handle the peak load, the only way to move the average load into the 50–80 percent sweet spot for efficiency is to break it up over multiple motors—which means redesigning the existing process.)

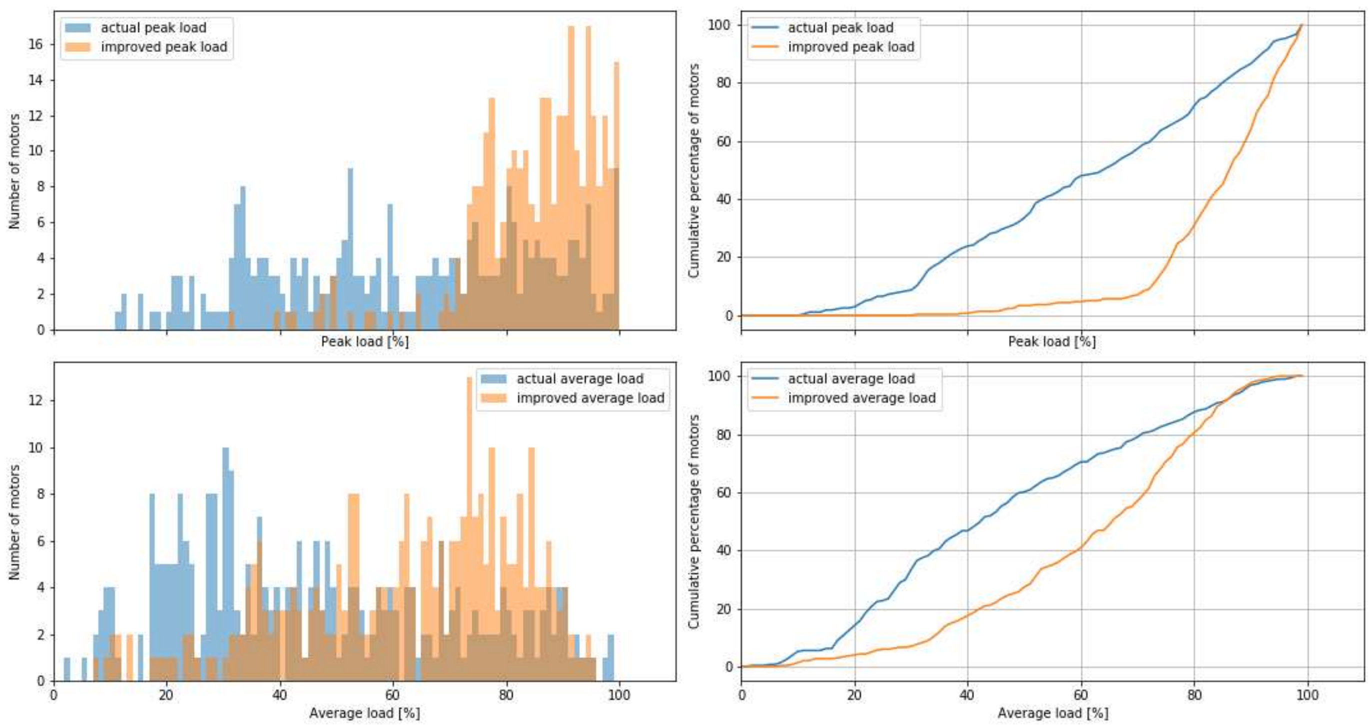


Figure 7. Peak and average motor load for our sample set after righsizing.

We also broke down our numbers by motor size, with expected results (figure 8). Almost by definition, a smaller motor will be closer to the optimal size for the process it runs in, meaning the real energy wins come from replacing larger motors. Yes, larger motors are more efficient than smaller ones—but only when they're being taken full advantage of. A "more efficient" motor that mostly runs at 20 percent load wastes more energy than a "less efficient" motor that mostly runs at 70 percent.

The real energy wins come from replacing larger motors.

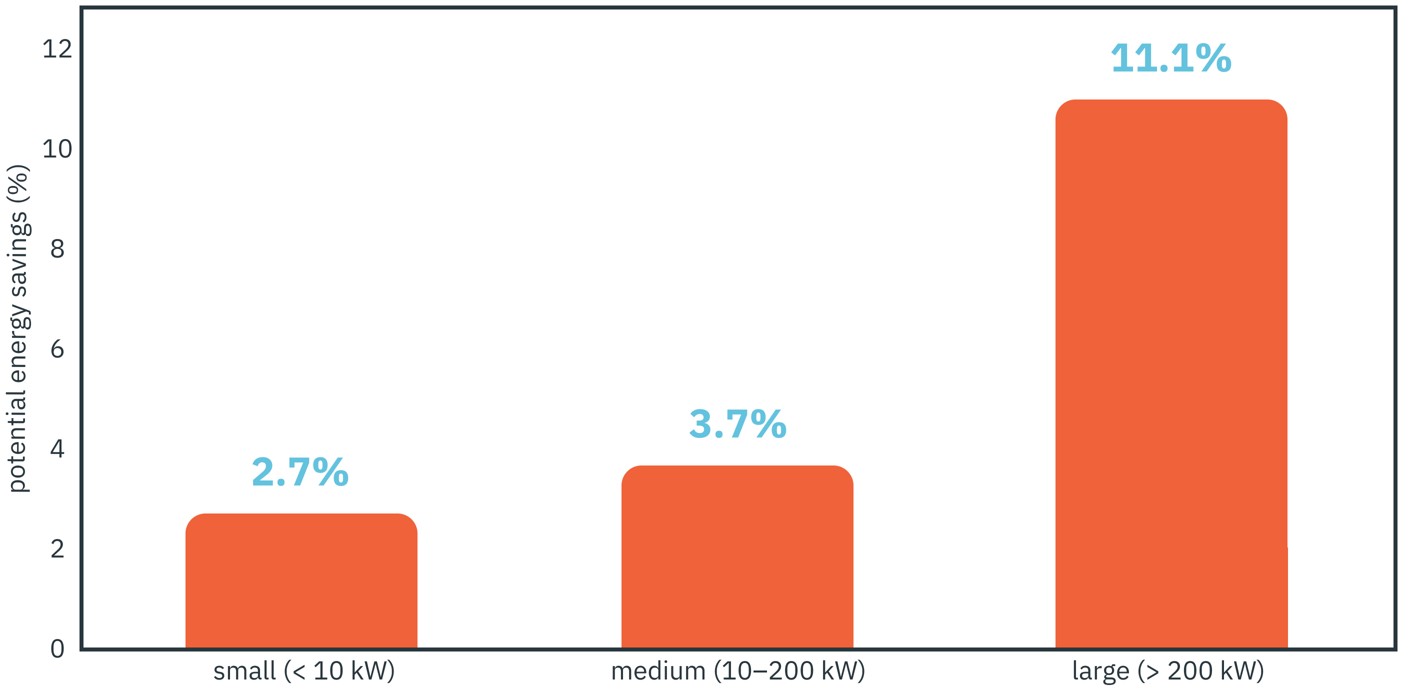


Figure 8. Average energy savings broken down by motor size.

Putting it all together

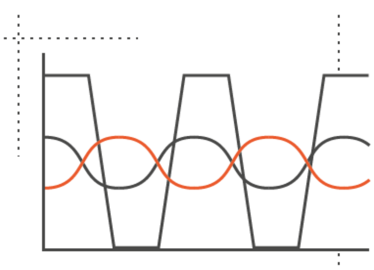
So now we know which of our motors and processes are wasting energy. How can we put those insights to good use?

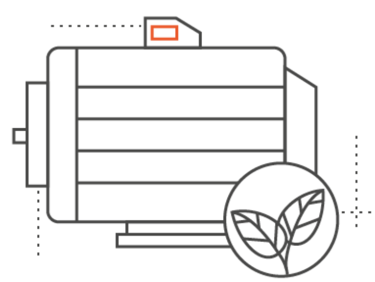
Saving energy in industry isn't easy, but at 43 percent of global electricity consumption, it's well worth the effort and cost. No other human endeavor has as much potential to reduce our demand for power.

In this paper we looked at the low-hanging fruit, and the answer there seems fairly easy to define: replace the existing motor with the optimal one. (Easy to *define*, mind you, not always easy to execute. It's a huge undertaking to replace an asset, let alone redesign a process.)

Sometimes the fix is even simpler to identify: suppose your process runs three small pumps that average 80 percent load during the winter, when there's lots of rain, but only 20 percent in the dry summer. An obvious first step is to run just one of the pumps during summer, raising it to 60 percent load (and using no energy for the other two).

But maybe your process uses a single large pump. **The fix here is much more invasive**: replace the large pump with three small ones. **But the fix also has more potential.** Now that you're redesigning the process, you could make it even more efficient than the one above, by choosing four even smaller pumps that together can handle the winter rain. Now you run just one of the four in summer, raising it to 80 percent load—and building in redundancy as well.





Monitor. › **Detect.** › **Act.**

Data to help drive informed discussion

There are four main ways to reduce the energy wasted by industrial motors:

> Use motors in a higher efficiency class.
> Catch developing faults earlier.
> Use the smallest motor that will do the job.
> Optimize the underlying processes.

In this paper, we've seen how technology designed for the second point can also provide you with actionable data on the last two points. We looked specifically at motors whose peak load far exceeds their average load, but that's just one example. Whatever the parameters of your motors and processes, SAM4 can tell you exactly how they're performing. From motor efficiency to a real-time pump curve, our mission is to extract maximum value from current and voltage signals. These insights don't offer a quick fix, but they can inform data-driven discussion on how your company can best achieve the sustainable 3Ps: people, planet, and profit.

Tom Gankema

Passionate about solving the problem of unplanned downtime, Semiotic Labs uses AI-driven electrical waveform analysis to create smart condition monitoring solutions that increase productivity while saving customers' time and money.

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