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Editor's Desk

Overcoming Imposter Syndrome

For the past 5½ years as editor-in-chief of the *International Journal of Energy Management* (IJEM) for the Association of Energy Engineers (AEE) [and for the 3 years before, leading one of AEE's previous journals], I have been inviting you (yes, you, the one currently reading this journal) to write and submit an article for publication. When I attend AEE events, my main task is to meet people, learn what they do, what they have to offer, and invite them to write an article and submit it to the journal. During my recent trip to Bellevue, Washington, to attend AEE West, I spoke to a plethora* of people. Since returning from the AEE event, I have been inviting even more people (the speakers at the event, whom I did not have the chance to meet) to turn their presentations into articles for the benefit of those AEE members who could not attend the event.

One of the common responses I get when I speak to a person is "I have not done anything worthy of publication in an AEE journal." The misconception is that unless the topic is the savior of energy management, a miracle of energy engineering, or has saved a client millions or billions of dollars, or some other type of silver bullet, the accomplishment is not noteworthy.

I hear things like, "Why should I write a paper? All these people [around us at this event] know more than I do.

"The journal's audience/readership have heard it all before.

"I haven't done anything new; I just do what I know (over and over again)."

Another one is "I learned it from others who are more knowledgeable and more experienced than me."

If you feel this way, my response is "Bunk!" All of this is just a form of imposter syndrome.

Imposter syndrome is the feeling of self-doubt—that you are not worthy of your accomplishments or even praise. It's a condition of feeling anxious or not feeling success internally. The condition often results

*Yes, this is a joking tribute to the movie *Three Amigos*. Give yourself a bonus point if you knew this one.

in people feeling that they are a fraud, or a phony, or just lucky (rather than talented)—basically doubting their own abilities and/or accomplishments.

> An idiom I frequently say is "I'd rather be lucky than good." It's a phrase I heard from another, and I locked onto it. It's meant to be humorous, but it's also a mild form of imposter syndrome because it credits luck more so than skill.

A long time ago, I was feeling a bit timid before presenting a technical paper to a large audience. My mentor noted my trepidation and reminded me that the people in the audience were there because they wanted to learn what I had knew. I had something valuable to offer and they were there for it. If I did not have something valuable to share, they would not have been in the audience—but there they were, filling the room. I was not an imposter. Furthermore, as a member of AEE, I am willing to bet neither are you.

Imposter syndrome is not a case of "fake it till you make it." In fact, it is quite the opposite. Fake it till you make it means you are not as talented as others think you are. Whereas imposter syndrome means you are talented, others recognize it, but internally you do not feel as talented as others know you are.

As I recently presented to an audience, "Have you completed anything in the last year or year and a half?" That is your topic. Write an article on that topic It does not have to be new, or even innovative. (Ok, bonus points if it is.) It just has to be something you accomplished. It could be an audit, where all you did was make recommendations to a client. The client does not even need to have done anything yet. (Ok, bonus points if they have or plan to do so.) If you completed a project, you could tell the story about how you found the opportunity, how you completed the project, and the obstacles you had to overcome during the process. If the project has been completed for a while, can you compare expected/projected results to realized results. You might even discuss the measurement and verification plan used in the process.

I don't want my discussion to focus only on projects. (This is a bias of my background.) If you wrote an energy management plan for your company or a client, there is value in explaining the process from beginning to end—even hopes for deploying and implementing the plan over time.

One of the goals of your article should be to communicate with the potential reader that if you can do it, then they can do it. Don't fool yourself into thinking, I can't write an article on this old hat, it's been done before. I am here to tell you, that unless it has been done everywhere (and I do mean everywhere), then someone needs to hear about it. Your one-extra story could be the final factor in motivating others to move forward with their own activity.

The U.S. Department of Energy recently received massive funding to promote the expanded use of air-source heat pumps. This technology was "old hat" when I got into the industry (over 40 years ago). However, the efficacy of the technology has considerably improved even since the last time I replaced the air-source heat pump on my last house.

Bottom line: if you are successfully employed in the energy management industry, the odds are good that you have accomplished something recently (within the past few years). That means odds are good that you are not an imposter and that you have a valuable story to share with your fellow AEE members. I want you to tell that story.

I understand that writing does not come easy to some people. I also understand that it takes time and effort. However, as I have written in a previous issue of IJEM, there are benefits to writing and I believe the benefits can make the process worth the effort.

I look forward to hearing from you.

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Op-Ed

Thinking Bigger about What's Possible with Energy Auditing

Herbert Dwyer

A recent study found that the rate of building retrofits would need to triple to achieve our climate goals*. A colossal increase like this cannot be achieved by making a few tweaks to the existing process. The only way we can begin to address this problem is by igniting a collective vision for a more ambitious approach to energy auditing. Specifically, we must challenge conventional norms, champion the power of creative thinking, and emphasize the pivotal role of technology.

Of course, renewables are vitally important in achieving climate objectives, but when talking about retrofitting buildings we need more than a photo op and the "hoopla" surrounding a new rooftop solar install. Ultimately, the nuts and bolts of reducing greenhouse gas emissions in buildings is found in reducing consumption from mechanical and electrical equipment.

The truth is that every one of these building retrofits begins with a time-consuming, in-person energy audit. Drawing on the sobering statistics from State and Federal governments, EMPEQ has calculated that, to reach America's climate goals, we must reach a pace of 7,100 building retrofits daily from now until 2050†. Further, when you consider the conversion rates of energy audits to retrofits, this would mean a staggering 35,000 audits need to happen every day. Lastly, exacerbating this issue is the fact that there is a trifecta of challenges within the energy auditing sector's workforce: limited labor availability, requisite

*Burns, J. US will need to triple building retrofit rate to meet decarbonization targets: report. Utility Dive. June 27, 2023. Available at https://www.utilitydive.com/news/building-retrofit-decarbonization-targets-jll-report/654004/. Accessed May 25, 2024.

†LaClair, D. Innovation in Site Surveys and Energy Audits Can Help Reach Climate Goals by 2050. EMPEQ. Available at https://empeq.co/innovation-in-site-surveys-energy-audits-can-help-reach-climate-goals-by-2050/. Accessed May 25, 2024.

skill shortages, and insufficient audit capacity. It is clear that a paradigm shift is not only necessary but imperative to effectively address both the need to increase the rate of retrofits and the pressing workforce challenges.

Fortunately, there are several emerging technologies available to increase capacity of the existing workforce, lower the barrier to entry into the energy auditing workforce, and/or reimagine the way energy audits are conducted. My company, EMPEQ, epitomizes this effort with our innovative Fast Site Survey software—an app that uses Artificial Intelligence (AI) to instantly identify equipment/parts, digitize specifications, and glean insights like remaining useful life, cost/energy saving alternatives, and many others all from a smartphone picture. The product not only makes existing auditors more efficient, but, because of the app's embedded intelligence, it expands the candidate pool for site auditors.

However, EMPEQ is not alone. Other technologies can be deployed to overcome some of these challenges listed above. For example, blockchain can be used to create a single record of truth for a building's service and maintenance history—this is helpful for buyers, sellers, owners, and, of course, energy efficiency contractors. Additionally, unmanned aerial systems (UAS), specifically swarm technologies, can create instant 3D models by sending a large number of miniature drones into a building's footprint; this can be used to assist with the initial retrofit plan to make buildings more energy efficient. Further, digital toolsets like RETScreen and EnergyStar Portfolio Manager bring automation to many steps in the auditing process.

All these technologies combined make crowdsourcing energy audits a distinct possibility in the near term. My vision for the future of our industry features community-wide energy audits being achieved in weeks—not months or years, as it takes today. In this vision, entry-level workers, homeowners, and other ratepayers swiftly collect basic building and equipment data processed by AI. EMPEQ's Fast Site Survey would be the perfect data collection tool, but there is a plethora of energy modeling software platforms also powered by various forms of AI and machine learning that could produce actionable results.

Ultimately, scaling up energy audits is the sole path forward if we are to meet our 2050 climate goals. The pressing need to expedite progress will only occur with an open-minded and curious approach. As such, my call to action is to challenge the status quo and push boundaries to secure a sustainable future. The urgency of the message cannot be overstated, and I believe it is incumbent upon all of us to heed this call and contribute to the transformative change needed for a greener, more sustainable world.

Herbert Dwyer is co-founder and CEO of EMPEQ, a software development and financial technology company serving the commercial HVAC, energy engineering, and building equipment industries. Herbert Dwyer may be contacted via email at herbert.dwyer@empeq.co.

Op-Ed

A Conundrum

John Avina

An interesting conundrum I find in the energy audit industry is the client's mindset. Many of our clients want an energy audit to save money on utility costs. We, meaning, energy auditors, provide them with great recommendations for what they can do. They invest in these projects, and they save money on utility bills. The entire exercise for the client is one of saving money. So, many building owners will interview several energy auditing firms and pick a low-priced firm to do their audit. This makes sense. The building owner is trying to save on energy costs. Why not save on the energy audit cost as well? This is totally logical.

The problem with this approach is that you usually get what you pay for. Low-cost audits usually mean you are getting inexperienced people who don't really understand HVAC or HVAC controls very well. They are going to miss the best energy conservation measures (ECMs), which are usually HVAC-related. Low audit prices also imply that the consultant isn't planning on investing very many hours in the analysis and the report. You get what you pay for.

It is funny—if you want to save money, you must spend money, and that is exactly what someone looking to save money wants to avoid doing at all costs.

Good luck explaining that to a purchasing department!

John Avina, CEM, CEA, CMVP, CxA, has worked in energy analysis and utility bill tracking for over 25 years. He is currently the CEO of Abraxas Energy Consulting. John may be contacted via email at john.avina@abraxasenergy.com.

Case Study: Compressed Air—Maximizing Energy Efficiency by Matching Air Supply to Plant Air Demand

Vikesh Punwassi

ABSTRACT

Air compressor systems are energy intensive systems with low energy efficiencies. It is therefore essential to ensure maximized energy efficiency throughout its operation. This study focused on the option of matching the supply to the plant's demand of compressed air. This article presents a case study in which a 20-year-old 200-kW fixed-speed oil-cooled rotary-screw compressor was successfully replaced with a 55-kW variable speed drive (VSD) controlled air-cooled rotary screw compressor, because the plant's compressed air requirements had significantly reduced from the time the original system was designed and commissioned. The air flow rate of the plant was modeled, using a power analyzer, to understand the exact requirements of the plant. Thereafter, the VSD compressor was selected because it can match the supply to the demand as well as having a lower turn down ratio (TDR). This project was able to reduce the energy consumption thereby also reducing the carbon emissions by 49%, while also lowering the noise levels improving stability of the line pressure.

INTRODUCTION

The supply of compressed air in any industrial facility can be one of the most expensive and energy intensive systems and if not continually monitored and managed, it can become a very inefficient system.

This case study involved a compressor system in an automobile production facility that was successfully upgraded using variable speed drive (VSD) technology and as such, will attempt to cover the following:

1) Steps taken to understand the plant's compressed air requirements using only a power analyzer.

2) The method used to model the VSD to match the supply to plant's demand.

3) Discuss the results of the energy saving measure.

Background Information

This project was implemented in a manufacturing plant with its core process in the employ of welding operations in which pneumatic jigs are used for both robotic and manually operated fixtures. This is a critical process plant that could not afford downtime to the production process especially with regards to the maintenance and operation of the utility equipment.

A schematic representation of the compressor system is shown in Figure 1.

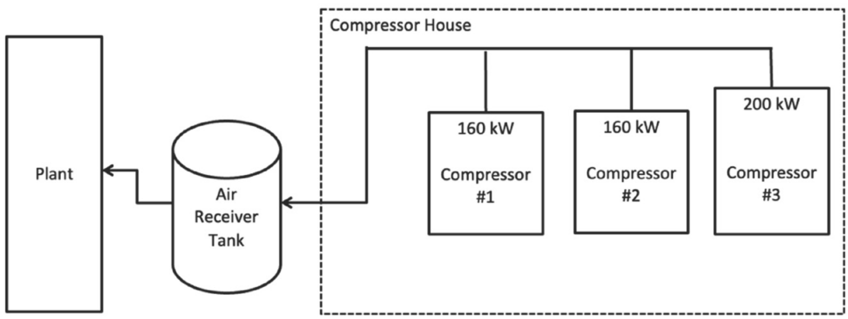

Figure 1.
Schematic Representation of the Compressor Configuration at the Plant

At the Time of this Project

1) The plant had significantly reduced its production output and had decommissioned a few production lines. This therefore presented a huge energy saving opportunity because the demand for compressed air had reduced significantly and many pneumatic tools were eliminated from the production lines.

2) The compressors were more than 20 years old, their maintenance proved to be very expensive, and spare parts were fast becoming obsolete.

3) Compressor 1 (160 kW) had already failed.

4) Compressor 2 (160 kW) was operated during the nightshift when production volumes were lower, and Compressor 3 (200 kW) was operated during the dayshift when the production volumes were higher.

5) The line pressure required by the plant was 6.8 bar; however, this was not stable.

6) The air reticulation and jig fixtures had numerous air leaks.

7) There were pressure gauges at various points in the line but no other instrumentation to indicate air flow rates or power demand of the system at any point in the operation.

DESIGN METHODOLOGY

As with any system, especially so when implementing an energy saving opportunity (ESO), the measurement and verification is a very important process that must take priority to accurately quantify the savings. This step is also required for the analysis of the system under study.

The real power demand was logged for a period of 1 week at 15-second intervals. The data was then prepared to form an average load profile representing a full day. A 10-minute snapshot of the logging is shown in Figure 2 in which the loading and unloading patterns can be clearly seen.

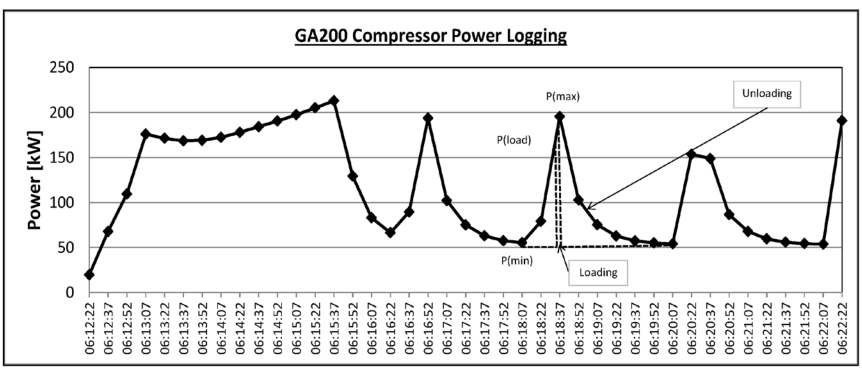

Figure 2. Snapshot of Compressor Load and Unload Cycles for a 10-minute Log at 15-second Intervals

To accurately estimate the load point of the compressor, the following exercise was completed.

$$P(load) = 0.7 \times [P(max) - P(min)] + P(min) \quad (1)$$

$$\text{Load Point} = 1, \text{ If } P(actual) > P(load) \quad (2a)$$
$$= 0, \text{ If } P(actual) < P(load) \quad (2b)$$

The power data analysis revealed a 13% duty cycle for the compressor, confirming that the compressor had become oversized for the current application. The 10-minute average power demand for a full production day can be seen in Figure 3.

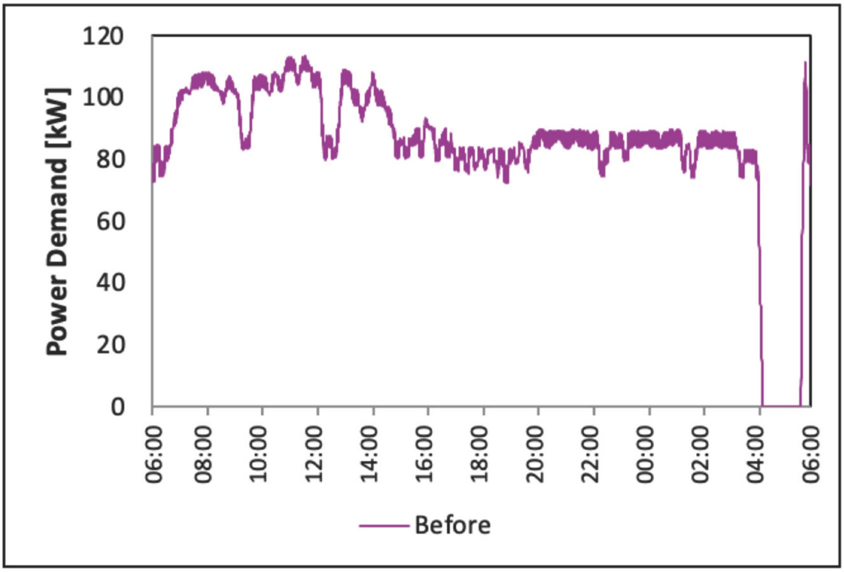

Figure 3. Average Power Demand of the 200-kW Compressor for a Full Production Day

$$\text{Air flow rate } [N\text{-}m^3/min] = 29, \text{ if load point} = 1 \quad (3a)$$
$$= 0, \text{ if load point} = 0 \quad (3b)$$

Equations (1) through (3) form the logic and the basis for the analysis and by working out the 10-minute moving average of the data, the graphical representation of the air flow rate was produced and is shown in Figure 4.

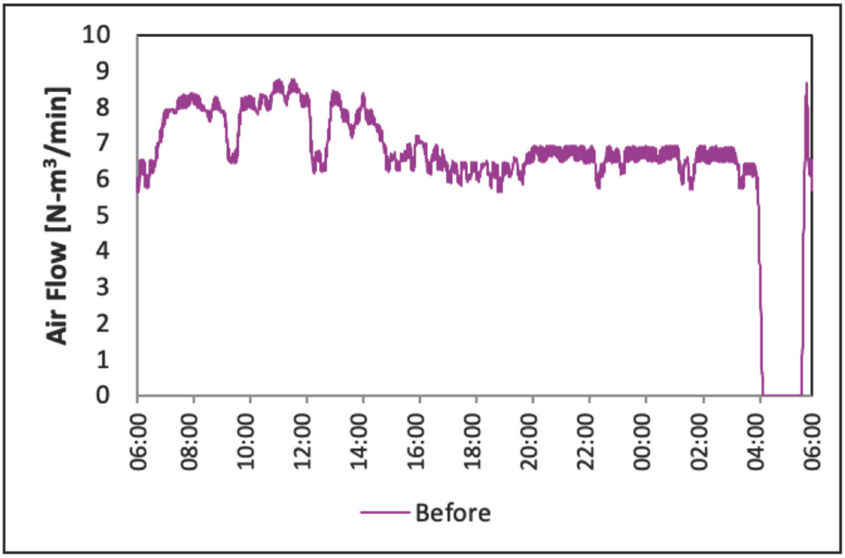

Figure 4. Average Air Flow Rate Demand from the Plant

VSD technology was employed for these main reasons:

1) Lower turn-down ratio (TDR).
2) Increase in energy saving by matching supply to plant demand of compressed air at any point in time thus, reducing the waste of over-supply as produced from the fixed speed compressor 3 (200 kW), as shown in Figure 1.
3) Excellent monitoring features enabled continuous monitoring and easier trouble shooting.
4) Air leaks can also be visually represented, by using the human-machine interface (HMI) during non-production times. This makes it easy to quantify and track the progress of fixing air leaks.

From the Department of Energy (DOE) [1], it was understood that the power from a VSD compressor has a linear relationship with the air flow rate. A variety of VSD compressors were researched and a 55-kW oil-free, air-cooled unit was selected to model the power based of the plant's air flow rate at any point time. This compressor was selected because it could meet the whole range of the plant's air demand with some spare capacity.

Figure 5 shows the maximum and minimum power and air flow rate for the compressor. This method was used to work out the parameters required to model the VSD power using the air flow that is shown in Figure 4. This approach provided the means to:

1. Estimate the power consumption as if the 55-kW VSD compressor was installed and operated.
2. Quantify the energy savings and air leaks in the system.

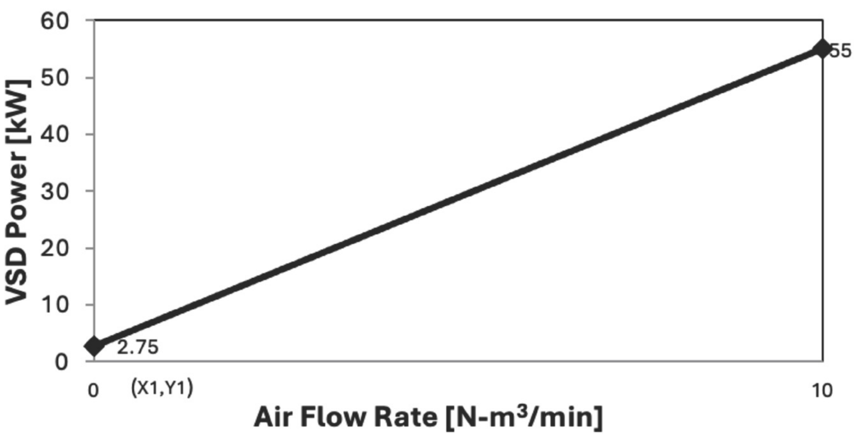

Figure 5.
Power and Air Flow Rate Relationship in a 55-kW VSD Compressor

The gradient, m, can be determined out as follows.

$$m = (Y2 - Y1) / (X2 - X1) = (55 - 2.75) / (10 - 0) = 5.22 \quad (4)$$

$$Power = (5.22 * Air\ Flow\ Rate) + 2.75 \quad (5)$$

where,
Power = kW
Air Flow Rate = N-m^3/min

An important point to remember when estimating the power consumption is that as long as the compressor is switched on.

1) The minimum power, in this case, will be 25% of Max, idle state = 13.75 kW

2) The minimum air flow rate, in this case, in idle state = 1.5 N-m^3/min.

These checks had been built in the spread sheet to automatically work this into the energy saving calculations.

RESULTS

The Atlas Copco GA200 was decommissioned and the 55-kW VSD was installed and commissioned. The power was logged, and the air flow rate was measured, logged, and stored in the built-in memory storage facility of the HMI.

The power demand can be clearly seen in Figure 6. The corresponding air flow rate is shown in Figure 7, which shows a very similar pattern to the before condition showing that the original air flow rate modeled in Figure 4 was correct.

A summary of the results is shown in Table 1, which indicates that to supply a similar air flow rate, the new compressor system consumes 49% less energy, while matching the supply to the plant demand and constant

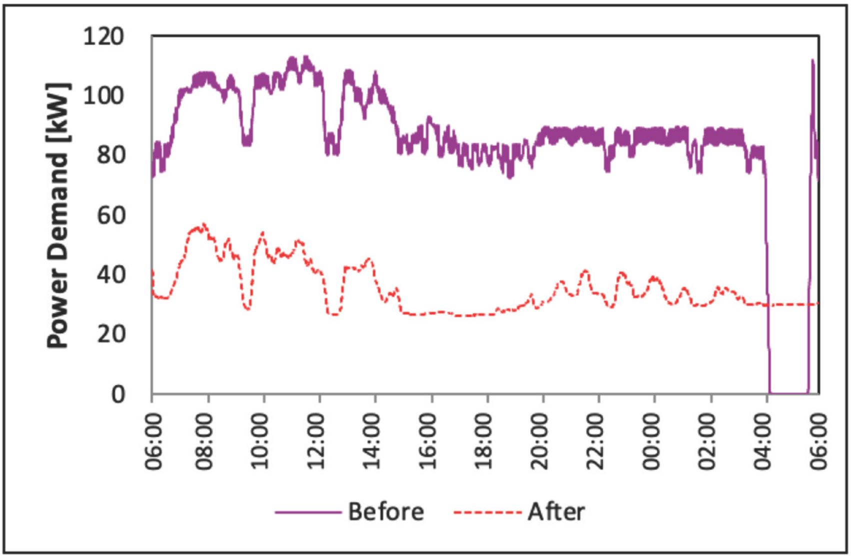

Figure 6. Comparison of Compressor Demand Before and After

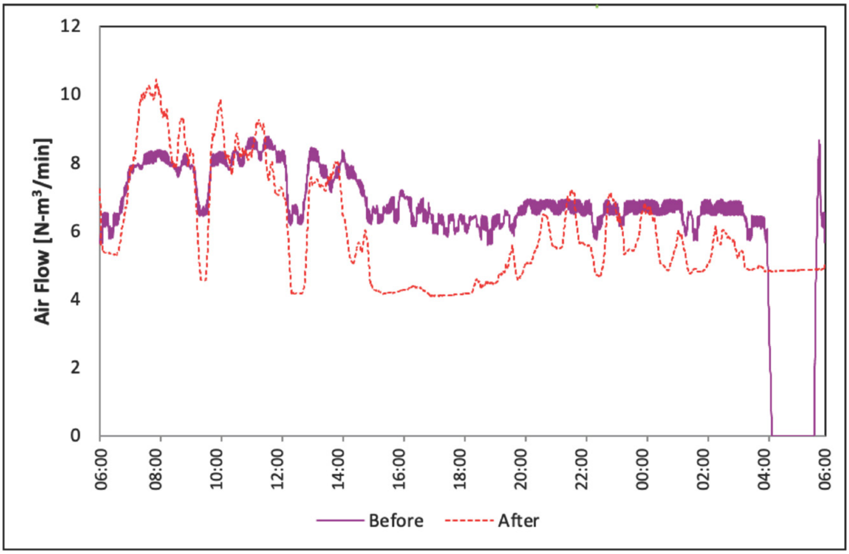

Figure 7. Comparison of Compressor Air Flow Rate Before and After

Table1. Comparison Between Before and After Energy Saving Measure

	Before	After	Savings
kWh/month	44,513	22,5009	22,013
kg/CO_2	42,643	21,555	21,088

pressure of 6.8 bar. The carbon emission factor 1 kWh = 0.958 kg CO_2 was used.

MEASUREMENT AND VERIFICATION

The measurement and verification process of this project employed the use of Option C per the International Performance Measurement and Verification Protocol (IPMVP) [2].

This exercise was completed to verify the savings obtained from the direct equipment measurement (Option C). The baseline was constructed by using the plant's historical energy data and production volumes. The anomaly production months were removed as this skewed the accu-

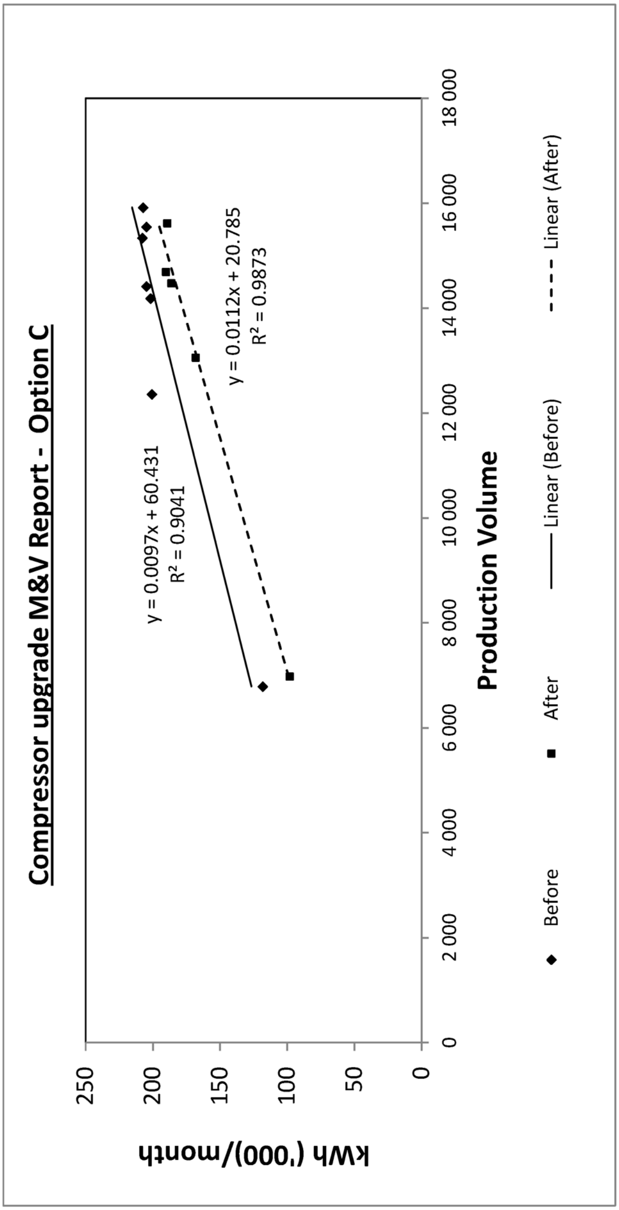

Figure 8. Compressor Upgrade Comparison from the Measurement and Verification Report

racy of the data. The regression analysis was applied, and the baseline equation was derived.

After the implementation of the project, the energy consumption and production volumes were tracked and plotted. The average energy savings were within 10% when compared to the data in Table 1.

RECOMMENDATIONS

Further to this project, the following recommendations were made to improve the overall system.

1) Decommission compressors 1 and 2 (160 kW) machines from Figure 1.
2) Install a 45-kW fixed-speed, air-cooled compressor to supplement the 55-kW VSD compressor during plant start-up and other anomaly conditions where there is a surge in air demand.
3) Investigate the potential for a heat recovery system using the lubricant oil circuit in the compressor, which is at approximately 70°C, to heat water for ablution wash basin and showers which are within 50-m proximity of the compressor house.

A proposed layout is shown in Figure 9, which includes full system redundancy.

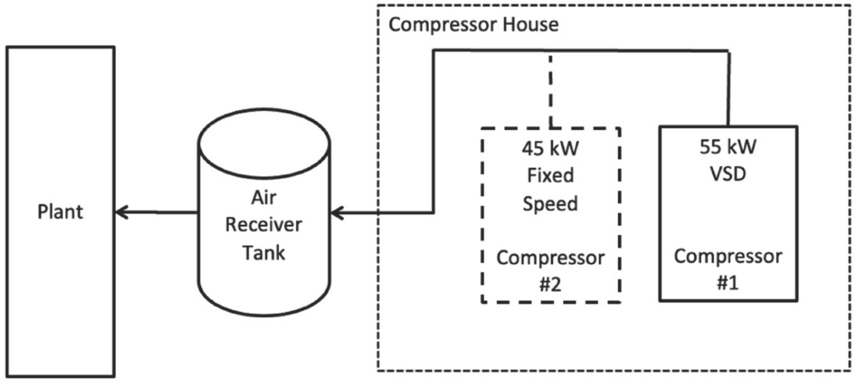

Figure 9. Proposed Layout of the Upgraded Compressor House

CONCLUSION

When the opportunity to upgrade a system presents itself, especially the energy intensive systems such as an air compressor, one cannot simply just do a one for one replacement. The system was originally designed and commissioned for a different set of parameters and constraints, which would in all probability have changed over the course of time.

There is huge benefit in using a scientific approach by applying first principles to understand and model the system so that the accuracy identifying the correct specification of the new equipment, which has an overall benefit to the project (e.g., better return on investment, increased system efficiency, lower maintenance, and operating costs).

This project took advantage of the opportunity to replace and reduce the size of the large inefficient compressors with a smaller and more efficient one. In addition, the energy costs were further improved by using VSD technology to match the supply to the plant's demand for compressed air. This could only be accurately quantified by modeling the original configuration and in turn, using that model to predict how the new system will perform for the same operating conditions. Care needs to be taken to build in extra capacity to account for an increase in air demand in the future.

This project realized an average of 22,013 kWh/month energy savings and reduce carbon emissions by 21,088 kg CO_2, while still providing a 40% spare capacity for future increases in air demand. This project also freed up space in the compressor house due to the reduced footprint of the compressor unit.

A further benefit of this project was to identify that during non-production times, the air flow rate was 4 N-m^3/min. After fixing the air leaks, the air flow rate was reduced to 2 N-m^3/min. Without the HMI screen continuously displaying the parameters of the compressor, this would not have been an easy and quick task. By quantifying the air leaks, the HMI encourages team members to identify and repair these leaks. The HMI shares the results of the system, showing team members the difference they can make, and improving the competitive edge of the business by reducing utility costs and maintaining asset integrity.

The project also noted the following additional benefits:

1) Lower noise levels in the compressor house.

2) Reduced production down time and product defects due to stable / consistent line pressure.

References

[1] US Department of Energy (DOE). 2016. Improving Compressed Air System Performance: A Sourcebook for Industry. Third Edition. Developed for the DOE Compressed Air Challenge Program by the Lawrence Berkeley National Laboratory and Resource Dynamics Corporation. DOE/EE-1340. (Pg. 49). Available at https://www.compressedairchallenge.org/data/sites/1/media/library/sourcebook/Improving_Compressed_Air-Sourcebook.pdf.

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Harmonic Energy— A Parasitic Electrical Load You Don't Need

Duane D. Warren

ABSTRACT

Harmonic energy is a parasitic load on the electrical system. It increases power losses and the utility bill. In addition, it can result in meter inaccuracy, often producing even higher readings that look like you are using more electricity than you actually are. In many cases, harmonics can inflate the electrical bill by as much as 10% to 20%!

Correcting these harmonic issues will reduce utility costs and nuisance breaker trips. Correcting harmonic issues will also tend to reduce conductor temperatures and increase worker safety.

WHAT IS HARMONIC ENERGY?

Normally, electricity is delivered to buildings in a 60 Hertz (Hz, 60 cycles per second) alternating current (AC) waveform. The current moves back and forth by way of electron flow, carrying and delivering voltage to the load. Each electron carries a bit of voltage, moves forward from one atom to another, transfers the voltage to another electron on another atom, and then moves back. It takes a lot of electrons to make the current we use, so special materials are used as conductors. They are selected because they can move a lot of electrons easily without heating up too much or degrading. Typically, these conductors are copper, and sometimes aluminum.

Figure 1 shows how current moves back and forth (up and down in the chart, positive to negative) in a typical circuit. Note that the voltage is also moving back and forth (up and down in the chart, positive to negative). The current is also lagging a bit behind the voltage, which is typical for most electrical circuits. This happens because the movement of current (and voltage) creates a circular magnetic field around the conductor.

Because there are often multiple conductors next to one another in large circuits, the magnetic fields in adjacent conductors interfere with one another. Because the magnetic fields and the power flow are interactive, the magnetic field interference will slow down current flow. This lagging effect is more prevalent in motor circuits and is often called an inductive load.

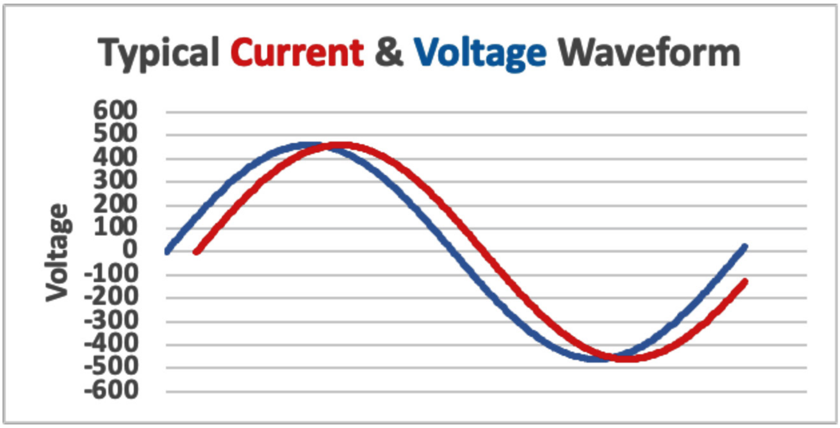

Figure 1. Typical Current and Voltage Waveform

You will often hear that harmonic energy is created by switching in electronic circuits. The word "switching" often suggests something like light switches or a similar type of On-Off switch. This is not exactly the case. What the word "switching" refers to is what is happening inside electronic circuits. All electronic circuits use "Ones" and "Zeros" to work and communicate with one another. On and off, several thousand times per second. A typical computer has as many as 300 million transistors, so that's a lot of switching on and off. Each transistor in a computer operates at about 5 volts. The on and off switching doesn't quite work perfectly—there is a little bounce when the circuit is turned on (the signal goes up a little higher than desired) and off (the signal goes down a little lower than desired). This excess positive and negative switching energy will combine on a device. Because this is happening a lot faster than 60 Hz, it creates some excess voltage and current that is different from the supply power to the device. Some of this energy goes to the electrical ground, and some of it goes back into the power supply.

If you have a lot of computer equipment (like a server room—lots of little circuits adding together) or big variable speed equipment (like a large variable-frequency drive (VFD)—big circuits switching high current), there will be some additional energy pumped back into the power supply circuit. Some equipment comes with special filters to prevent this, most do not. Some systems have special power wiring to deal with this, most do not. This additional harmonic energy creates a power supply that can look like Figure 2.

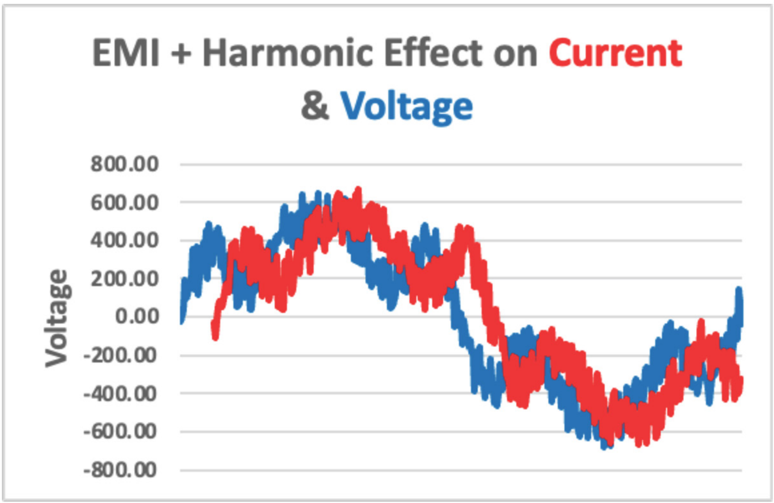

Figure 2. EMI plus Harmonic Effect on Current and Voltage

As you can see, the waveform is not so orderly anymore.

Because the circuits switch a lot faster and at varying speeds, the power waveform gets a bunch of other waveforms of different frequencies (often up to 500 Hz) and different energy levels (sometimes up to 20% of the base energy use). This forces more of the harmonic energy carried inside the conductor to the outer edge of the conductor (about the outer ⅓ of the conductor diameter). This excess harmonic current in the conductor exterior increases the temperature of the conductor, sometimes so much that it will cause nuisance trips at the circuit breakers. As well, the increased harmonic current at the outer edge reduces the current carrying capability of the conductor (since some of the current at the outer edge is moving in a different direction at times). This increases the power losses of the conductor, which under normal conditions is supposed to be quite small. For gear heads, this movement of current to the outer edge is caused by skin effect and proximity effect. These effects are significantly increased when harmonics are present.

Skin Effect

Skin effect is a current flow effect that pushes some of the current to the outer ⅓ of the conductor at higher frequencies. It occurs because the higher frequency current is sometimes moving in reverse flow to the primary 60-Hz current. A 60-Hz primary current moves electrons back and forth 60 times per second, transferring voltage with each jump. When a 300-Hz harmonic current is added, the harmonic current moves electrons back and forth 300 times per second, transferring voltage with each jump. So, sometimes there is harmonic current moving against the primary current. Like an obstruction in a stream, this temporary obstruction of harmonic energy is pushed to the outer edges as the main current goes about the business of transferring power to the load. Usually this is the outer ⅓ of the conductor. The inner ⅔ of the conductor must work harder to overcome the losses on the outer skin by conducting more power.

Proximity Effect

Proximity effect is a current flow effect that is caused by the magnetic field of adjacent conductors, particularly if harmonic energy is present. Large current conductors are often made up of several smaller wires–it's easier and cheaper to install the smaller conductors in a bundle. The magnetic field of a conductor will hit both sides of the adjacent conductor, penetrating into the outer boundary layer. Harmonic energy tends to penetrate adjacent conductors and interfere in normal current flow to a greater degree because the magnetic field of a conductor with a higher harmonic load is much stronger.

In larger circuits, the conductors are usually made up of a group of smaller conductors connected in parallel and run in the same conduit. It's cheaper and easier to do this way. However, the proximity effect becomes more of a problem with this type of wiring method if there are harmonics present in the circuit. In this type of installation, it is very important to use wiring that is rated for dealing with harmonics. This type of wiring has specially constructed shielding, and the individual conductors are wound together in a specific manner. Both wiring characteristics help reduce skin effect and proximity effect.

Similarly, the magnetic field around the conductor doesn't look so orderly anymore. The added harmonics produce a magnetic field that is no longer uniform and is much stronger than in a normal circuit. It will tend to radiate a lot more energy out of the conductor unevenly which will affect other nearby electronic equipment such as breakers, meters, UPS devices, and high voltage switches. It can even affect generator controllers, causing the generator to go offline or fail.

This undesirable altered magnetic field is often referred to as electro-magnetic interference (EMI). Power circuits operating in a normal fashion produce a magnetic field and a small amount of EMI, but a power circuit under the same power load operating with a high harmonic energy component will produce EMI levels that are 5 to 20 times larger than normal.

So, why is all this a big deal?

Let's recap.

To produce the harmonic energy (which is useless and essentially wasted energy), the incoming power must be increased. You can't get something from nothing. Energy can't be created or destroyed, only changed in form. Einstein came up with this one—it's the first law of thermodynamics*.

Once the harmonic energy is produced, it very often finds its way back to the electrical meter. Remember that this harmonic energy has already been billed for once. Now that it's been generated onsite by a few misbehaving devices, it finds its way back to the incoming power meter. The meter sees this incoming harmonic energy and reads it. And adds it to the power bill.

It's been paid for once. The act of creating it is completely useless—it does no useful work. Then it gets paid for again when it is broadcast back to the utility meter. That's beside all the other deleterious effects of harmonic energy, like neutral current problems, vibration, nuisance breaker trips, premature equipment failure, derated power capacities, etc. Lurking around in this situation is the fact that the increased incoming power that is used to create the harmonic energy is essentially wasted. Harmon-

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*German physicist Rudolf Clausius is credited with making the first explicit statement of the first law of thermodynamics around 1850. The phrasing of the first law of thermodynamics has been refined several times since.

ic energy does not really do work at the end device it is feeding.

How much of a problem is this? It's not unusual for harmonics to add 20% to the baseline electrical load. The author has seen this value as high as 50%. That's a huge cost penalty, and a high risk of equipment failure.

It's important to note that the power losses due to increased harmonic energy vary exponentially with increased frequency. For a variety of reasons, the frequencies we are very concerned with are 3rd harmonic (180 Hz), 5th harmonic (300 Hz), and the 7th harmonic (560 Hz). This has a lot to do with how these frequencies line up with the 60 Hz base signal—they tend to amplify voltage and current levels and can cause some seriously bad neutral current and ground current levels. *This can lead to premature equipment failure (major equipment such as elevators, chillers, transformers, fans, fire alarm systems, BMS) and potential safety concerns for operators.*

Important Safety Note:

High harmonic loading increases neutral conductor currents. This can cause neutral conductor failure, grounding issues, or both. These problems can create unstable grounding and current flow to ground at end devices. The consequences of this can be deadly.

Many modern meters show harmonic loading on the display (with a little hunting around). There are measurement techniques to test for the presence of harmonics. It's best to look for this condition at several different times—it may be caused by equipment that runs intermittently.

CORRECTIVE ACTIONS

There are several ways to deal with harmonic energy and the related EMI.

1) A K-type transformer can be installed on the circuit with the harmonic load. This transforms the harmonic energy into heat at the transformer. It's not an ideal way to treat harmonic generation, but it does limit the transmission past the transformer..

2) Active Filtration—This is a device that is a combination of capacitors, inductors, and control equipment that changes its configuration to deal with a changing harmonic load. This can be an expensive option, and it certainly requires some very rigorous testing and analysis to select the right option.

3) 12 Pulse Transformer—This device acts as a phase filter on three phase devices. It does a very good job of harmonic mitigation on three phase devices, but less so on single phase devices such as servers or computers. This is the preferred method of dealing with harmonic noise generated by VFDs, or where the harmonic energy is consistent with little variation.

4) Harmonic Mitigation Transformer (HMT)—The primary and secondary windings in the transformer are specially tuned by custom interleaving, special wire insulation, special grounding, wire and cable sheathing, and other practices. They are designed and built to deal with specific harmonic energy problems and can handle more than one type of harmonic energy.

CONCLUSION

From the previous section, it sounds like the HMT is the best choice for many applications. It may well be for your specific application. If the harmonic energy is fairly consistent, it might be more economical to look at the 12-pulse transformer. In general, it is best to investigate and identify what is generating the harmonic energy and do some power quality analysis to determine the nature of the harmonic energy being generated.

AUTHOR BIOGRAPHY

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Unlocking Electrification with Hourly Emissions Data

Craig Sinnamon, David B. Goldstein, and Anna Kelly

ABSTRACT

International agencies are working to create a sense of urgency toward climate action. Specific actions such as replacing fossil-fuel-fired heating equipment with heat pumps, electrifying transportation, and energy storage are recommended. These broad actions will be evaluated and implemented at individual facilities. The carbon impact of buildings and industrial manufacturing must include the embodied carbon of the steel, wood, glass, and concrete used in construction. But you can't manage what you measure incorrectly. Currently the dominant method for measuring carbon emissions is to multiply energy consumption for each fuel by an emissions factor, using the average contributors to electricity generation. Relying on this method for cost assessments will undercut GHG emission reductions and lead to slower investment in necessary technologies. Recent standards have recommended utilizing long-run marginal contributions to electrical generation ("consequential analysis"). This study addresses the question: How much difference would it make for facility managers to use long-run marginal emissions rather than annual emissions in their feasibility assessments for measures at industrial facilities? We performed a comparative analysis using a sample of approximately 30,000 industrial facilities. We calculated emissions data using two distinct inputs: the eGRID (2021 annual average factors) and the Cambium (8-year average, 2023-2030) hourly long-run marginal emissions factors (as suggested in new draft standards). This comparison tests the hypothesis that using average impacts undercuts global policy goals such as electrification.

INTRODUCTION

The energy efficiency industry aims to contribute to stabilizing the electricity system, ensuring that future power planning aligns with public needs and policy objectives. As has been the case throughout the regulated utility industry's history, key priorities include safety, affordability, reliability, and abundance. However, with increasing investment and policy direction towards decarbonization and electrification, adjustments are needed to incentivize future capacity that aligns with these key priorities and promotes technologies essential for combating climate change and reducing emissions. These adjustments, if done optimally, can greatly reduce the cost of grid modernization by encouraging efficiency and controllability of demand to replace simple increases in kW capacity.

There are some technologies that we know will lead broadly to decreased greenhouse gas (GHG) emissions, such as industrial heat pumps and battery and thermal storage (IEA 2023). However, if a facility is considering such measures, the engineers and facility managers need to calculate the costs, feasibility, and present the technology's effect on the facility's overall GHG emissions over time. Predicting future emissions requires that the assumptions that get used in these models make sense and properly account for what would happen in the future (Gagnon and Cole, 2022). There are three primary ways to predict greenhouse gas emissions to inform these calculations: average annual emissions, short-run marginal emission rates, and long-run marginal emission rates. This article focuses on the difference between average emissions and long-run marginal emissions. Each of these concepts has appropriate use-cases based on their development and intent.

Emissions Rates for Engineers and Facility Managers

Why is this difference important? Because these technologies require significant investment and will be implemented one-by-one after careful consideration by decision makers who rely on the analysis analyses from their engineers and facility managers at each corporation, campus, facility, plant, or building. Facilities will be required to comply with efficiency standards, performance standards, and corporate decarbonization goals, and the engineers and facility managers representing those entities will make the case for which equipment makes sense after they calculate and compare the feasibility, cost savings, and GHG savings of specific measures. As standards improve and data available increases, the costs and paybacks from installing heat pumps to supply heat, industrial dryers, or thermal storage systems will be significantly impacted by operation calculations taking into account the impacts of operating during hours when grid electricity is cleaner and when the grid is dirtiest.

These estimates not only affect whether the manager in charge of the facilities of interest approves the improvement, but also others that may be involved in the go/no-go decision: utilities, state or federal government energy efficiency/decarbonization advisors, accountants who review emissions disclosures, etc. The early years of including carbon estimates in cost analyses will face additional scrutiny to ensure compliance with all applicable standards and requirements.

Recalling back to the concept of average emissions and long-run emissions, we have identified that using one or the other leads to significant differences in the cost and emission outcomes of a feasibility assessment for the aforementioned high-interest technologies such as industrial heat pumps, dryers, and storage. Some (or perhaps most) economically and technically feasible projects will appear to fail to reduce GHG emissions significantly, or even at all, if the analysis uses average emissions. This conclusion is not well documented in the literature because published papers usually focus on successes—such as why a particular project achieved its goals—rather than failures. And it is a failure when viable and necessary projects are not implemented because the preliminary analysis erroneously did show lackluster GHG emissions reductions. This research begins to correct this failing and provide support for upcoming data and standards on GHG emissions analysis for these technologies. Although it may be common within engineering circles and utility industry conference settings to discuss the comparison between nascent and legacy methods, research with the best possible available data is necessary to demonstrate how to implement the newer methods in cost analyses and feasibility assessments.

This article will discuss show the differences in GHG emissions from the legacy and nascent inputs and provide guidance on how to correct the errors that underlie current GHG calculations. It will evaluate the magnitude of the error, demonstrating that it makes a big difference in most grid regions in the U.S., and thus likely in most grids everywhere, and provide a path forward for decision makers, engineers, and technology developers to make recommendations and decisions that lead to a better way to reduce GHG emissions.

SUMMARY OF EMISSION RATES

Average Emission Rates

Average emission rates are a simple metric used to evaluate the environmental impact of energy production and consumption. As such, they are the most commonly used metric in 2024. Unlike marginal emission rates that focus on changes in emissions due to specific shifts in demand or supply—and are thus harder to calculate-- average emission rates provide a broad view of emissions over a given period in the past, typically a year. They can be useful for assigning or attributing responsibility for past actions, being based on historic data, but are not the best choice for evaluating the consequences of future actions.

The widely used World Resources Institutes Greenhouse Gas Protocol, first issued around 2014, establishes this method. (WRI 2001)

For example, consider a region with a mix of energy sources including coal, natural gas, nuclear, and renewables like wind and solar. The average emission rate for this region would be calculated by considering the emissions associated with each energy source and their respective shares in the overall energy mix. Average emissions assume that the grid and the capacity mix of the area in question are static factors that are not impacted by the energy projects and policies that may be passed over the lifespan of a measure.

Short-Run Marginal Emission Rates

This metric represents the emissions that would arise if new load were added to the system in the short term, usually within minutes or hours. These emissions are evaluated based on the power sources that would come online immediately to meet the additional demand. Often, these power sources include less efficient or higher-emission plants that are only dispatched during periods of high demand or operational constraints. Understanding short-run marginal emissions is important for real-time decision-making and optimizing grid operations.

Long-Run Marginal Emission Rates

The concept of long-run marginal emission rates involves estimating the emissions that would either increase or decrease due to a change in electric demand. This estimation takes into account not just how the change affects current grid operations but also how it influences the overall structure of the grid, including the addition or retirement of capital assets like generators and transmission lines. This distinguishes it from short-run marginal emissions, which assume that grid assets remain fixed.

For a deeper understanding of these metrics, one can refer to "Planning for the evolution of the electric grid with a long-run marginal emission rate" (Gagnon and Cole, 2022).

There will be both short-term and long-term consequences to many interventions. Long-run marginal emissions will provide a more accurate model of today's operational decisions and the long-term impacts of changes in demand on the grid as the grid changes and evolves in response to them. A long-run marginal emission rate is what can be used to identify what the reduced emissions would be of a specific intervention, such as industrial heat pumps.

It can be illustrative to put yourself in the place of a facility planner to decode which metric may be useful to assessing your long-term emissions impact.

EMISSION RATE USE CASE

At a facility level, average emissions are helpful in benchmarking exercises to assess the environmental impact of a utility customer's energy consumption over time and compared to other, similar facilities. By comparing the average emissions of a facility to industry standards or regional averages, or by comparing an industrial facility's specific energy consumption or carbon emissions to its peers, as done by the Energy Star® program, planners can identify opportunities for improvement and set targets for reducing emissions. This metric can help planners track progress towards sustainability goals, such as reducing carbon footprints or achieving energy efficiency certifications. It provides a view of the environmental performance of facilities and guides decision-making on energy efficiency measures and investments.

This metric gave very similar results to marginal emissions when the most-used protocols for evaluating greenhouse gas emissions were developed but has increasingly diverged from the marginal emissions metric as grids throughout the world began relying more heavily on intermittent renewable energy sources such as solar and wind. As this article will show, the divergence has become large when considering the real grids in the U.S. in the 2020s.

When needing to make responsive, day-ahead, plans, the user may want to consider short-run marginal emissions to assist with real-time decision making on energy use within facilities. For example, during periods when short-run marginal emissions are high, the facility can choose to prioritize energy-saving measures like load shedding, shifting non-essential operations to off-peak hours, or temporarily reducing energy-intensive activities. Understanding short-run marginal emissions helps planners optimize energy usage within facilities to minimize environmental impact and potentially reduce energy costs during peak emission periods.

When considering retrofits to electricity-consuming facilities, retro-commissioning projects, or major capital improvements, the facility will want to rely on long-run marginal emissions: Long-run marginal emissions are valuable for creating long-term strategic planning and investment priorities. By considering the broader implications of grid changes and policy shifts on emissions over time, the user can anticipate future emissions trends and plan sustainable strategies accordingly. Long-run marginal emissions allow the user to evaluate the impact of adopting renewable energy systems, implementing energy storage solutions, or investing in energy-efficient technologies. This metric guides strategic decisions that contribute to long-term sustainability goals and resilience against changing energy landscapes.

DATA SOURCES

The Emissions and Generation Resource Integrated Database (eGRID) is a comprehensive database managed by the U.S. Environmental Protection Agency (EPA). It provides detailed information on power plants, their emissions, and their fuel sources across the United States. eGRID is a valuable tool for researchers, policymakers, and the public to understand the environmental impact of electricity generation, including greenhouse gas emissions such as carbon dioxide (CO_2), sulfur dioxide (SO_2), and nitrogen oxides (NOx).

The Cambium data sets, maintained by the National Renewable Energy Laboratory (NREL) and illustrated in Figure 1, provide simulated emissions, costs, and operational data for a set of modeled scenarios. The Cambium dataset is updated annually and provides scenario modeling of emission, cost and operational metrics for the U.S. electric sector through 2050. The models project the evolution of the grid and how it will meet demand subject to operational and policy constraints and incentives.

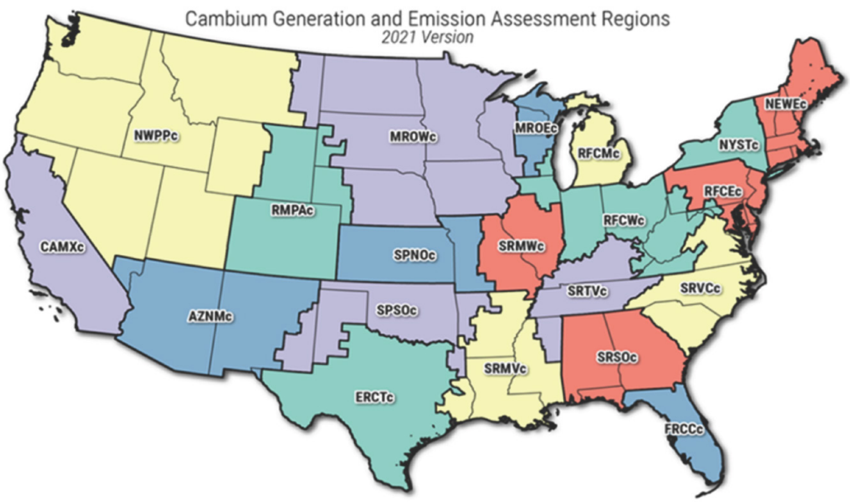

Figure 1. Cambium Generation and Emission Assessment Regions Map (2021 Version)

METHODOLOGY

For the analysis, we used data from the 2022 Cambium dataset. The dataset represents a series of scenarios that contain different mixes of technology, fuel, growth, and policy impacts (Gagnon et al., 2022, 2023). The Cambium scenarios use the ReEDS data which include a variety of policy scenarios, regulations, and technology inputs (Cohen et al., 2019). The 2022 scenarios include a mix of tax credit phase outs, but for brevity's sake, we are not including them here.

The scope of this analysis is looking at manufacturing facilities across six Cambium regions and identifying the extent to which long run marginal emission rates (LRMER) differ from average annual emissions from the eGRID database.

Table 1. Cambium Scenario Descriptions

Scenario	Description
Mid-case	Central estimates for inputs such as technology costs, fuel prices, and demand growth. No nascent technologies. Electric sector policies as they existed in September 2023.
Low Renewable Energy and Battery Costs	Mid-case with lower renewable energy and battery costs.
High Renewable Energy and Battery Costs	Mid-case with high renewable energy and battery costs.
High Demand Growth	Mid-case, with high electrification represented with a 2.8% average growth in demand from 2022 through 2050.
Low Natural Gas Prices	Mid-case with lower natural gas prices.
High Natural Gas Prices	Mid-case with higher natural gas prices.
95% Decarbonization by 2050	Mid-case with inclusion of nascent technologies a linear decrease in emissions to 5% of 2005 emissions by 2050.
100% Decarbonization by 2035	Mid-case with inclusion of nascent technologies a linear decrease in emissions to 0% of 2005 emissions by 2035.

Note: For more details and data on each scenario, refer to NREL Scenario Viewer (https://scenarioviewer.nrel.gov/?project=0f92fe57-3365-428a-8fe8-0afc326b3b43&mode=download&layout=Default).

Methodology

We chose to compare a data source for average annual emissions, eGRID, to a data source with long-run marginal emissions, Cambium, to identify which source would lead to incentivization of electrification for industrial customers in six geographic regions as shown in Table 2.

To ensure that only industrial manufacturing facilities were included in the analysis, NAICS codes were predicted using Power TakeOff's proprietary machine learning algorithm. This algorithm predicts NAICS codes based on properties of the facilities as obtained by their electric

Table 2. Cambium Regions in Analysis

Cambium Region	Geographic Region
RFCEc	Maryland
SRMWc	Southern Illinois
RFCWc	Greater Chicago Area
NWPPc	Washington State
SRSOc	Georgia
NEWEc	Connecticut

or gas utility. The algorithm generated NAICS codes and an associated confidence in the accuracy of that NAICS code. The accuracies are binned into 'High', 'Medium', and 'Low' confidence. To include only industrial manufacturing, we restricted our analysis to those facilities that the NAICS prediction algorithm identified as manufacturing (NAICS codes 31, 32, and 33 with 'High' confidence. This machine learning approach was taken due to missing data and other data quality issues in the data sources used for this analysis. Such an approach is not needed for individual engineers or facility managers conducting project or facility level analyses, or for policy makers who can use high quality data available for their region,, but was a necessary step for an analysis of this scale that relied on the hourly interval data provided via the supplying electric utilities.

For the emissions data, an 8-year average (2023-2030 inclusive) was constructed from the Cambium data to use as our comparison using the low renewable energy and battery cost scenario for this analysis. We chose the scenario bolded in Table 1 to harmonize with the carbon emissions metric used for residential buildings in ANSI/RESNET/ICC Standard 301 and ANSI/ASHRAE/IES Standard 90.2. These standards, in turn, chose this scenario based on the observation that meeting the IPCC's climate goal will require substantial increases in renewable energy, and we want electricity- consuming facilities to optimize for the likely future grid. (Kruis, et. al. 2022). This choice will assure that if the utility sector does its job in meeting the 1.5 C climate change goal, utility customers will project and achieve their goal.

Total annual emissions were calculated for approximately 33,308 facilities using the 2001 eGRID annual factors and the Cambium 8-year average derived from the 2022 Cambium dataset low renewable energy and battery costs scenario. Those facilities were reduced further to a final 3,900 flagged with high confidence of their NAICS code. Although we had industrial sector data for 10 of the regions, only six regions had sufficient data to continue the analysis. We required that each region have at least 50 facilities after all other restrictions were applied.

The Cambium LRMER data is provided in month-hours, 24 data points for each month of the year representing the average LRMER for each hour of the day during each month. The energy consumption data used in this analysis was hourly kWh smart meter data. To combine these two datasets, the 12x24 data points from the Cambium LRMER datasets need to be aligned with the 8760 data points representing one year of hourly data for a facility. To do this, for each facility, and each month of the year, the average 24-hour day consumption profile was calculated resulting in 12x24 data points for each facility representing the month-hour energy consumption patterns at the facility and aligning the consumption data with the Cambium LRMER data.

With this, the ratio of Cambium LRMER to eGRID annual average emissions was calculated for each facility.

This ratio was constructed using the sum of the product of the month-hour kWh consumption described above and the month-hour marginal lbs CO_2 emissions from the constructed 8-year LRMER average divided by the total annual kWh consumption multiplied by the 2021 eGRID annual emissions factor. The result is a single number for each facility that represents the ratio of these two different approaches to quantifying emissions, the Cambium to eGRID ratio. When this number is larger than 1, the eGRID method gives lower emissions than the Cambium method. When this number is equal to 1, both methods give the same emissions. When this number is less than 1, the eGRID method gives higher emissions than the Cambium method.

The distribution of these ratios as represented by a histogram of all the analyzed facilities in a region gives a large-scale sense for how these different methodologies impact the manufacturing facilities in these regions.

These histograms might be hard to interpret by some readers, so the next section looks at several hypothetical outcomes of the analysis and show what the resulting histogram would look like. This analysis is intended to clarify the significance of the analysis before the results are shown.

POTENTIAL OUTCOMES

There were several possible outcomes of this work. Below some of the possibilities are described along with visualizations of how the data would have looked in these cases. The data is visualized using ridgeline plots which show the distribution of the ratios similar to a histogram.* Note that this analysis is focused on electric data, and cost-benefit analysis outcomes from electrification measures are the vital interpretation of these scenarios.

Potential Outcome 1

There is no difference in using average emissions compared to using the LRMER.

In this case, shown in Figure 2, all the ratios are exactly 1, there is no difference between the average emissions and LRMER for any of the sites in any of the regions. In this case, it doesn't matter if a facility manager was to use one technique or another for measuring the impact of their electrification measures. There would be no difference.

Potential Outcome 2

There is a difference but is it not systematic across facilities. For half of the facilities, GHG emissions are higher when calculated using average emissions, and higher when calculated using LRMER for the other half.

Here in Figure 3, we see that while most facilities have a ratio close to one, indicating that the average emissions and LRMER give quite similar results, there are some examples where emissions calculated

*The data used in this section are simulated data used to describe these potential situations and build familiarity with the visualizations that will be used to describe the real findings in the subsequent section.

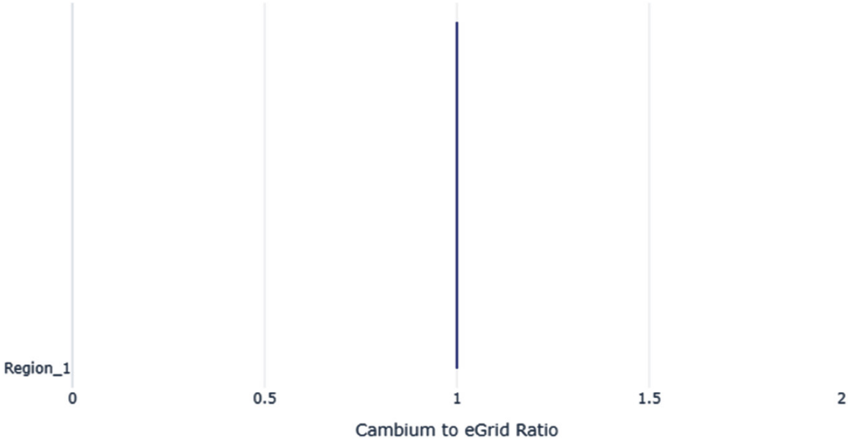

Figure 2. Distribution of Cambium to eGRID Ratios: Simulated Potential Case 1

using LRMER are only 70% of the GHG emissions calculated using annual averages, but others where the GHG emissions are 130% of the emissions calculated using annual averages. In the case where a cost-effectiveness test for a suite of electrification measures at a suite of campuses looked like this, the facility manager could compare between both methods and perhaps be more aggressive about electrification measures at some sites and leave them out at others.

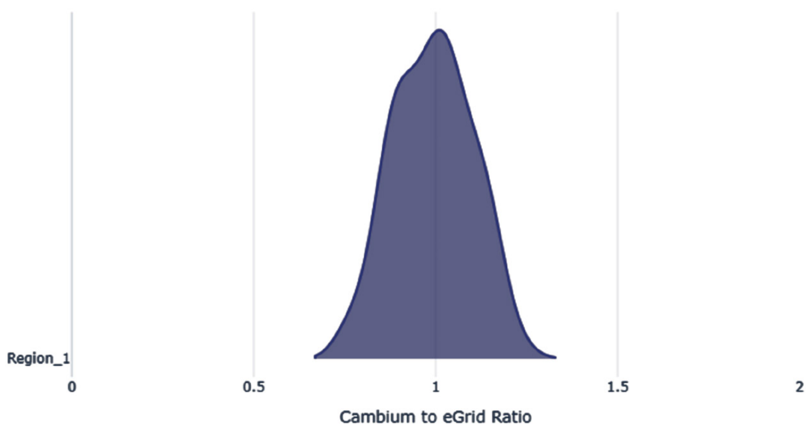

Figure 3. Distribution of Cambium to eGRID Ratios: Simulated Potential Case 2

Potential Outcome 3

Regional GHG emissions trend higher or lower depending on whether they are calculated with LRMER or annual averages, but it is not systemic across regions.

In this case, in region 1, GHG emissions calculated using LRMER are always higher than when calculated using annual averages, but in region 2 the opposite is true, and in region 3 it varies by facility but there is no notable difference between LRMER and annual averages. Also note that the width of the distributions may differ by region, with a larger width indicating more variation between facilities within that region. In this example, it may be useful to envision a national brand with facilities in three geographic regions analyzing pathways that to help them meet their decarbonization goals. If the results looked like they do in figure 4, the decision makers may choose to only conduct those upgrades in region 2, where it is clear that long-term GHG emissions will be best at meeting their decarbonization targets. Potential Outcome 4: GHG emissions are consistently lower when calculated using LRMER than when calculated using annual averages. This outcome is similar among all regions.

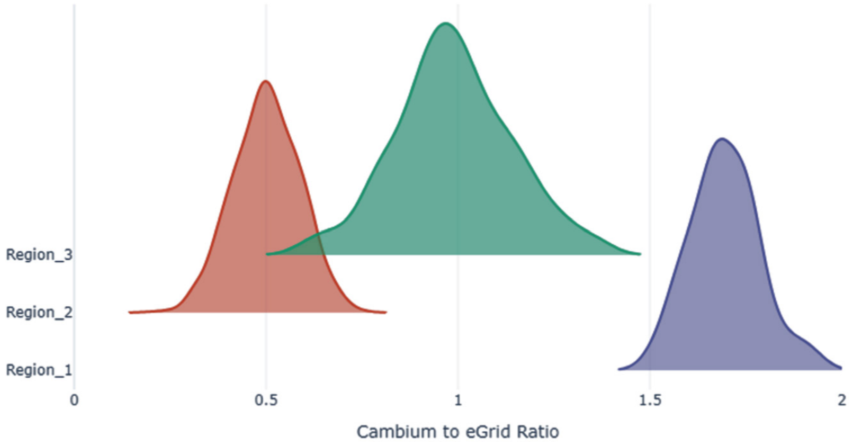

Figure 4. Distribution of Cambium to eGRID Ratios: Simulated Potential Case 3

Here, while there is some variation by facility, GHG emissions calculated using LRMER are always lower than emissions calculated using annual averages.

This outcome implies that substituting electricity for fossil fuels (whose impacts are nearly identical using all three evaluations methods) will be analyzed as emissions-reducing in more cases than average emission factors would predict, and that conducting those upgrades would be beneficial to the grid and the brand's decarbonization targets across the board.

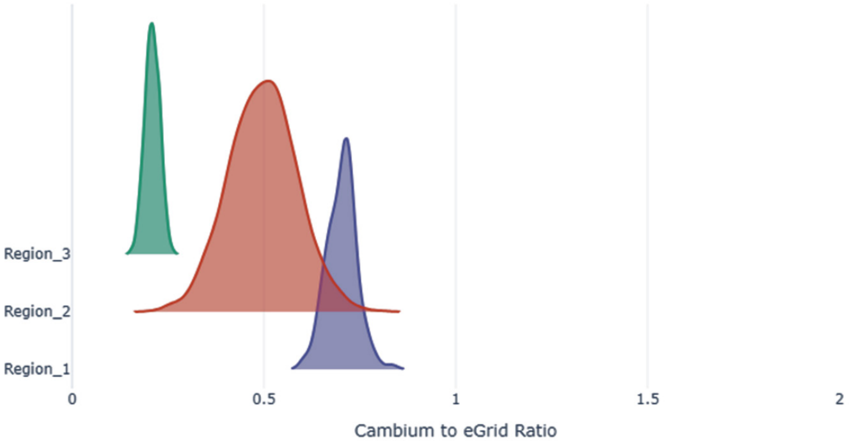

Figure 5. Distribution of Cambium to eGRID Ratios: Simulated Potential Case 4

Potential Outcome 5

GHG emissions calculated using LRMER are consistently higher than when calculated using annual averages, and that difference is systematic between regions.

In this final example, GHG emissions using LRMER are higher than when calculated using annual averages, In this case, substituting electricity for fossil fuels (whose impacts are nearly identical using all three evaluations methods) will be less attractive to facilities with decarbonization targets because the increased electric load will be interpreted as increasing emissions, rather than showing emissions reductions that are the result of a cleaner grid operating under real-world investment conditions.

FINDINGS

Figure 7 demonstrates the range of LRMER to annual average emissions distributions for the 3,900 facilities included in the final analysis

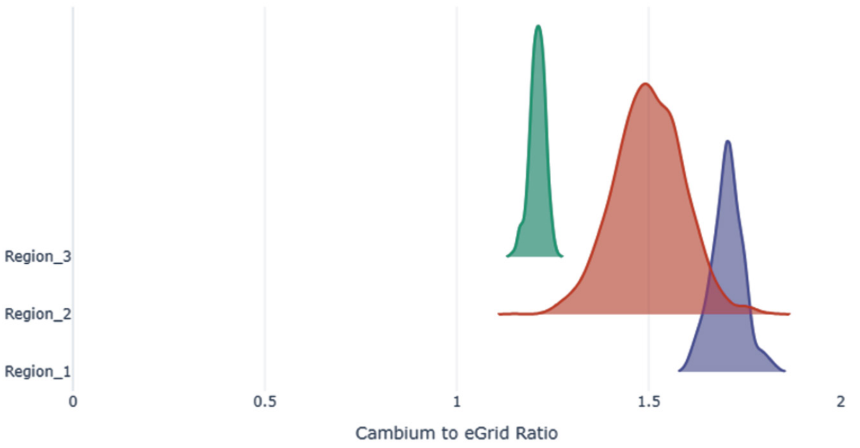

Figure 6. Distribution of Cambium to eGRID Ratios: Simulated Potential Case 5

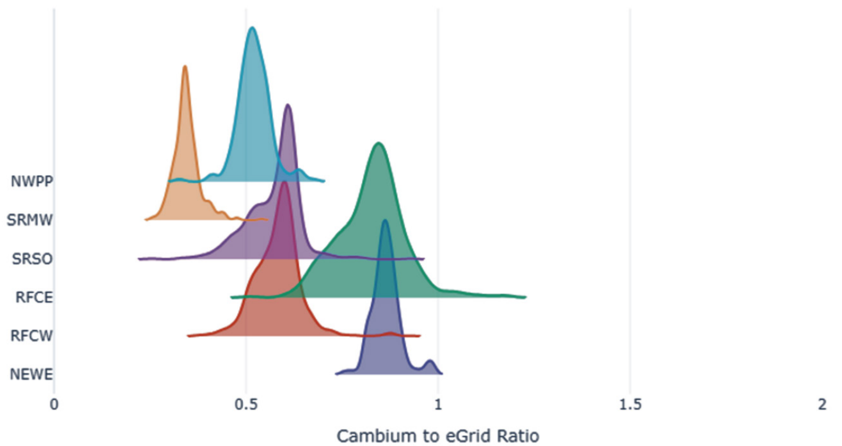

Figure7. Distribution of Cambium to eGRID Ratios Across Cambium Regions

dataset, by region. Recall these this data are using the scenario where renewable energy and battery costs are lower compared to other scenarios. (Past projections have consistently underestimated the renewables build-out.) In this scenario, in regions where the overall ratio is <1, the GHG emissions calculated using LRMER are lower than that of the emissions calculated using annual averages. Using LRMER emissions data to make the calculation allows for the individual facilities to meet decarbonization targets and claim GHG intensity for grid-beneficial measures than if the analysts were using annual averages to make their assessment. In short, using the LRMER for their measurement and reporting leads to decreased overall emissions compared to if they had used annual average.

Note what this does to projects that replace fossil fuels with electricity, such as heat pumps in buildings and industry, and charging of electric motor vehicles that replace fossil-fired car and truck engines.

The emissions of the electric alternative are lower than they would appear using the annual average emissions rates. But the avoided emissions from fossil fuels are the same.

Thus, heat pumps are (more correctly) evaluated as saving emissions in many circumstances when they might otherwise be evaluated (using annual average metrics) as not accomplishing much or even increasing emissions.

A similar outcome applies to batteries and thermal storage. For both technologies, there are losses in the storage process, which increases energy consumption. If we use annual average emissions rates, storage appears to increase emissions. Yet in the real world it can reduce emissions. The LRMER methods correctly account for this fact, while the annual average methods do not give storage the appropriate emissions reduction credit.

It is important to note that the variability of the ratios shown in Figure 7 is not due to random error, but rather due to plant-to-plant variations in the timing of electricity consumption. Detailed results show region by region descriptions of the ratio of GHG emissions calculated using LRMER compared to annual averages and provides in-depth analyses of two Maryland industrial facilities to provide further clarity.

Detailed Results

Southern Illinois (SRMWc) LRMER emissions range from 30 to 38% of annual average emissions for the majority of facilities, highlighting the impact of marginal emissions calculation. In the Greater Chicago area (RFCWc), LRMER with the low renewable energy and battery cost scenario falls within 45 to 65% of annual average emissions.

In Washington State (NWPPc) the majority of facilities exhibit LRMER between 46 and 55% of annual average emissions. In Georgia (SRSOc), LRMER emissions range from 40 to 65% of annual average emissions in this region. And last, in Connecticut (NEWEc), the LRMER rates fell between 72% and 103% of the average annual emissions.

In Maryland (RFCEc), most facilities exhibit LRMER emissions within 75 to 90% of annual average emissions, but outliers demonstrate significant differences depending on the facility.

We created some examples from Maryland, since Maryland is a state with planned changes to the grid to decrease carbon emissions over the next few years. While the state currently is powered by 12% coal, the state plans to eliminate coal generation by the end of 2025. Additionally, the state is powered by the Calvert Cliffs nuclear reactor which accounts for 39% of the state's generation.

Looking at facility level examples can illustrate the disconnect between emissions and consumption. See Figures 8 and 9 to see the consumption and emissions for a winery with annual consumption of about 500 MWh in Maryland (RFCEc region).

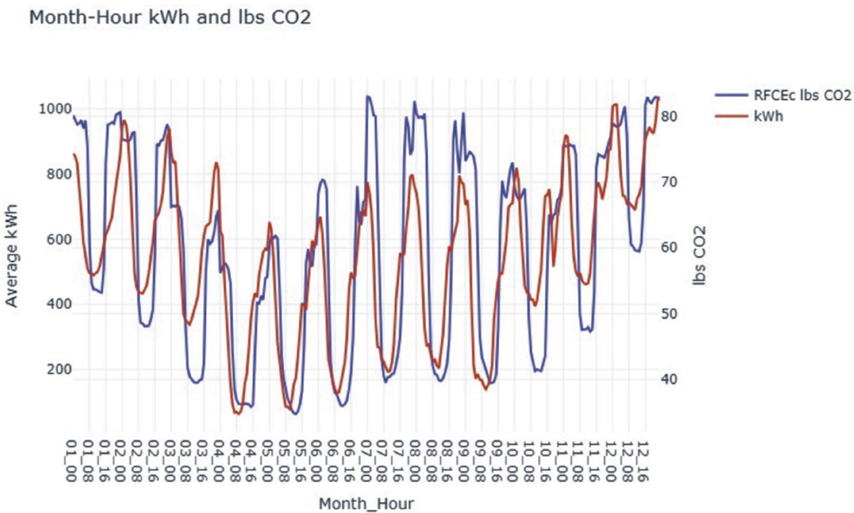

Figure 8. Consumption and GHG emissions for a Winery in Maryland

Looking at Figure 8 the winery shown has clear seasonal energy consumption patterns, with a winter peak. The emissions shown in blue are the state-level emissions for each month-hour. In this example, the facility's electricity consumption and GHG emissions peak during mid-summer. In the heatmap, the GHG emissions are most extreme overnight in the summer when the grid is taxed and lowest during the day when the

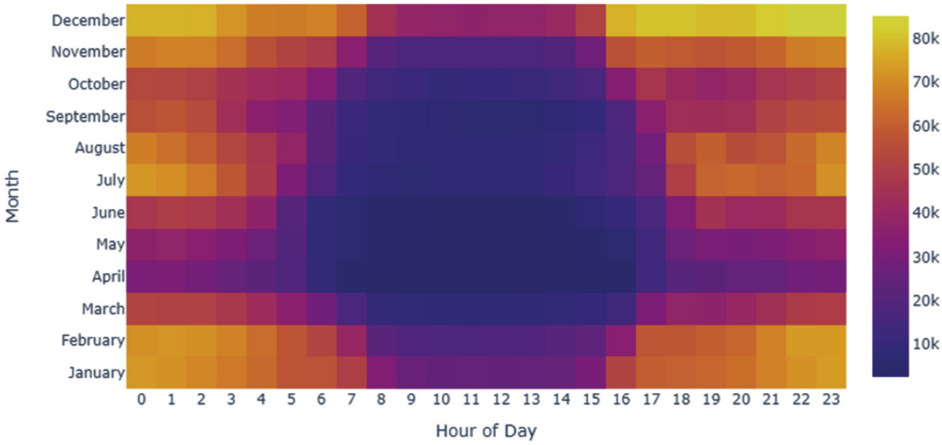

Figure 9. Month Hour Emissions Heatmap for Winery in Maryland

sun is shining, and renewable sources can carry the load. In this case, since the grid emissions and the electricity consumption are highly correlated, measures that reduce consumption throughout the year during the highest consumption times of the day will have the most significant emissions reduction impact as measured by LRMERs.

A second example, shown in Figures 10 and 11, is a pharmaceutical manufacturing facility with annual consumption of about 19 GWh, also in Maryland.

This facility also has weather or seasonally dependent energy consumption, but with a summer peak. In this example, GHG emissions are not as highly correlated with the facility-level energy consumption through the year. Because of how this facility operates, the strategies that this facility would employ to reduce emissions would be very different from that of the winery. Here the greatest potential for emissions reduction as measured using LRMERs will be realized overnight during the summer when both consumption and grid emissions are high.

LESSONS LEARNED AND CONCLUSIONS

The lower GHG emissions when calculated using LRMER compared to annual averages in each territory present an opportunity to

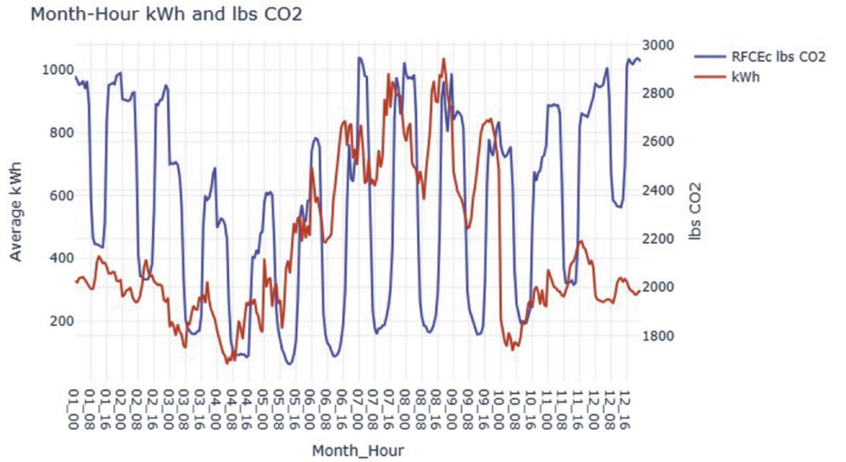

Figure 10. Consumption and Emissions for Pharmaceutical Manufacturing in Maryland

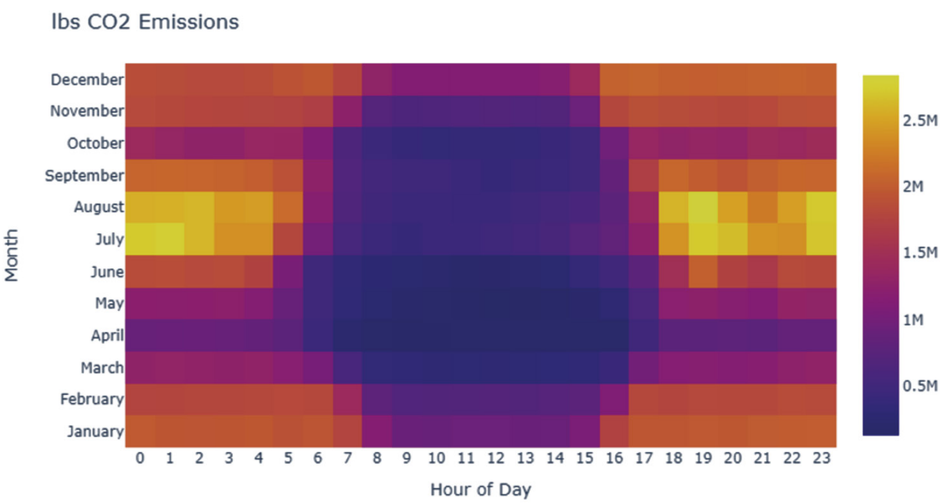

Figure 11. Month Hour Emissions Heatmap for Pharmaceutical Manufacturing in Maryland

accelerate electrification efforts. This acceleration results from more accurate estimates of the savings from fuel switching and demand flexibility that show greater savings than traditional methods. By prioritizing the use of LRMER over static annual average emissions, we can leverage this dynamic data to drive and optimize the transition towards greater electrification. We found a significant divergence between the two datasets that requires urgent action to ensure that the measure prioritization and measurement and verification (M&V) choices we make aren't jeopardizing investment in decarbonization projects that actually combat climate change. The conclusion found is that all studied regions show that we will encourage electrification more if we use hourly emissions data rather than annual averages.

There are some limitations to this work. We used the 2022 Cambium dataset rather than the 2023 dataset, as the 2023 dataset had not yet been released at the time that this analysis was initiated. Additionally, this dataset was limited to six geographic areas, rather than a full geographic spread due to the data that was available. Energy consumption patterns may vary between regions, and grid emissions whether average annual emissions or LRMER will differ as well. While this study provides valuable insights into the factors driving energy costs in certain regions, we recognize that the findings may not be directly applicable to other regions. Future research efforts to extend the geographic breadth of this work would be valuable.

We also used the LRMER Cambium projections exclusively. It would be useful to add to the body of knowledge on this topic for alternate research to ignore the 2025 Cambium projection and conduct short-run marginal emissions calculations using interpolations between recent observed data and the 2030 projections (Gagnon et al., 2023). In spite of these limitations, the results shown in this article demonstrate the value of LRMER.

As smart meters that collect and record hourly data and tools that make that data accessible become more common, using LRMER becomes easier to carry out. While data quality, data access, and regulatory compliance must always be considered, smart meter data is becoming increasingly accessible to individual energy managers. Many utilities provide portals that allow users to download spreadsheets with historical energy consumption data, and tools such as Green Button Connect My Data can provide programmatic interfaces to access the data as well.

Policy makers and other stakeholders will want to check their location specific climate action plans, GHG reduction laws, and other regulatory documents to identify if average annual emissions are being used in future planning, rather than LRMER, and adjust accordingly.

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Effects of Electric Utility Rates on Sustainability and Energy Efficiency in Industry

Gary Williams

ABSTRACT

The escalating trajectory of electricity prices in the United States underscores a critical concern for sustainability and energy efficiency, particularly in the industrial sector. Factors such as aging infrastructure contribute substantially to this trend, necessitating continuous investments in power generation and distribution systems. This article delves into the multifaceted impact of electric utility rates on industrial operations and explores strategies to mitigate the challenges posed by rising costs.

The complexity of electricity pricing dynamics, including diverse generation sources and regulatory frameworks, underscores the need for strategic responses. Energy efficiency and demand response programs emerge as crucial tools for cost mitigation, offering not only savings but also operational enhancements and alignment with sustainability goals.

Benchmarking mandates and incentives provide avenues for improving energy performance and reducing consumption. Collaboration with energy companies and investments in renewable energy further bolster long-term cost management and environmental stewardship. Initiatives such as retro-commissioning and energy treasure hunts leverage technology and grassroots approaches to enhance efficiency and foster sustainability culture. These proactive measures centered on energy efficiency, renewable integration, and cultural shifts offer viable pathways for industries to navigate the landscape of rising electricity prices and their associated challenges while contributing to broader environmental objectives and operational resilience.

INTRODUCTION

There's no humor in the staggering surge of energy prices in the United States, no matter how "shocking" they are. In all seriousness, electric utility rates profoundly influence industry sustainability and energy efficiency initiatives.

Higher utility rates lead to increased production costs and higher energy consumption, which in turn promote investment in energy-efficient technologies and sustainability measures, including renewable energy options.

The fact that energy prices have steadily increased by 5% (see Figure 1) over the past several years is a concerning trend. It impacts households, businesses, and overall economic stability. As we strive for sustainability and efficiency, finding solutions to mitigate these rising costs becomes crucial.

Several factors drive these increases, including aging infrastructure. The cost of building and maintaining power generation and distribution infrastructure, such as power plants, transmission lines, and substations, significantly impacts electricity costs.

According to the American Society of Civil Engineers (ASCE) [1], much of the country's infrastructure is well past its expiration date. Considering that the life expectancy of an overhead power line is between 25 to 30 years and the life expectancy of an underground system is 40 to 50 years, these systems are past their prime, requiring more maintenance and investments to keep them working. And some components are over 100 years old. Costs related to infrastructure—the maintenance, repair, upgrades, and distribution—are passed on to consumers through their energy bills.

Another key factor in rising energy prices is increased energy consumption. Electricity is playing a larger role. Projected growth for energy consumption between now and 2050 indicates a disparate increase for the industrial sector, the highest end-use sector (see Figure 2).

The expected increases are driven by companies adopting more electric systems, such as heat pumps and electric vehicle charging stations, and a significant shift toward electric arc furnaces in the steel and iron industries. Other sectors, such as transportation, residential, and commercial remain fairly consistent, mostly due to adherence to energy codes and more energy

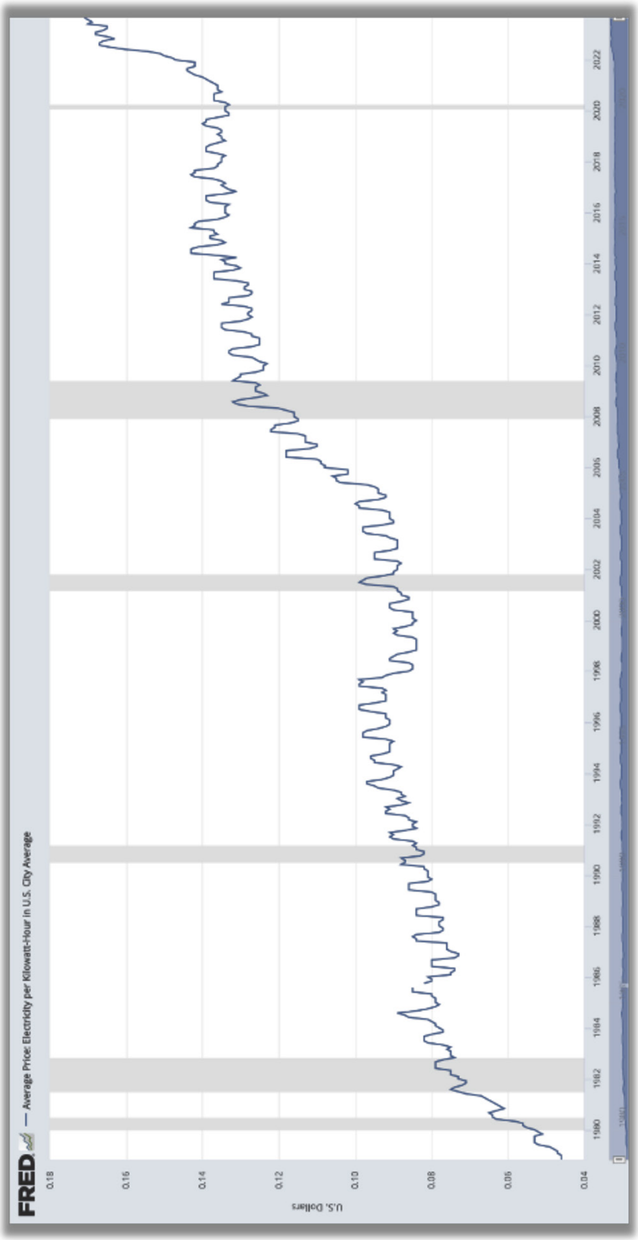

Figure 1. U.S. City Average Electricity Price per Kilowatt-hour (Source: https://fred.stlouisfed.org/series/APU000072610)

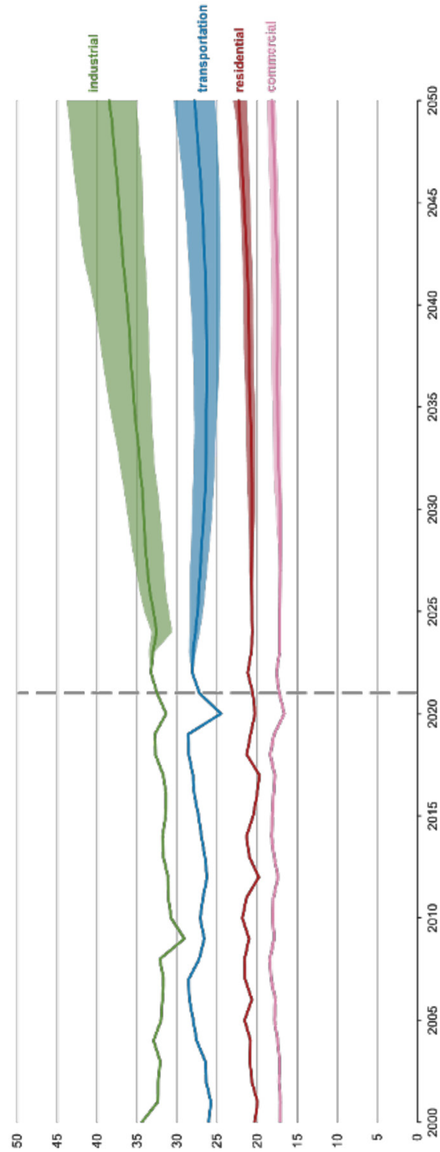

Figure 2. Energy Consumption Projected Growth
(Source: https://www.eia.gov/outlooks/aeo/)

efficient systems, particularly with regard to appliances for both residential and commercial.

Other factors affecting electricity prices include:

- Increased temperatures due to climate change: The cost of HVAC heating and cooling systems, both installation and upkeep, has increased dramatically.
- Generation sources: The cost of electricity can vary depending on the type of fuel used, such as coal, natural gas, or renewables like wind and solar.
- Regulatory policies: Taxes on carbon emissions or renewable energy mandates, for example, influence the cost of electricity generation sources.
- The push for renewable energy: Many companies are striving to become carbon neutral by 2030 and net zero by 2050. Although beneficial for the environment, the increased demand for renewable infrastructure requires investments from power companies in solar panels, wind turbines, hydroelectric, and geothermal systems. Like with maintenance and infrastructure, these investment costs are passed on to consumers.

Electricity prices are on the rise, influenced by the factors outlined above. There's little that can stop these inflating energy costs. However, there are programs and strategies organizations can adopt to help offset increases.

ENERGY EFFICIENCY AND DEMAND RESPONSE

It is not uncommon for large industrial manufacturing facilities to be paying more than $1 million per month for their electricity. With prices expected to rise by an average rate of 5% annually, this could result in an additional $50,000/month in electricity costs ($600,000 annualized).

Energy efficiency is considered the most cost-effective energy resource. A report from the United States Agency for International Development (USAID) [2] verified as much: a study of efficiency programs in 20 states over a three-year period found that the levelized cost per kilowatt-hour (kWh) for energy efficiency is one-third to half the cost of new electricity sources, such as wind, natural gas, coal, or nuclear.

By implementing energy efficiency measures, a factory, for example, could reduce its energy use by 20% while maintaining the same production levels, thereby freeing up capacity to be used elsewhere. Furthermore, energy efficiency can also lead to cost savings that can be invested in further capacity-building. Typical investment returns for energy efficiency projects, such as retrofitting, average 40% or higher [3], which is substantially more favorable than the 5% internal rate of return for renewable energy projects, even with subsidies.

Demand response reduces stress on the transmission system during peak periods of energy demand, allowing for increased transmission export capacity. By managing the energy use across the grid, demand response programs can reduce the need for additional transmission infrastructure or costly upgrades.

These programs also reduce system costs by energy shifting – adjusting energy use from peak periods to off-peak periods.

Benefits include:

- Reduced electricity rates: Lower rates during off-peak hours incentivize consumers to shift energy usage away from peak times.
- Peak load avoidance: By participating in demand response consumers can avoid higher charges for peak loads.
- Rebates and credits: Financial incentives are often available to help offset costs associated with implementing demand response strategies.
- Capacity payments: Utility companies may pay clients who commit to reducing their energy consumption during critical time periods.
- Environmental benefits: Reducing overall energy consumption contributes to environmental sustainability and aligns with some organizations' corporate sustainability goals.
- Enhanced grid reliability: By managing peak demand, utility companies can prevent blackouts and brownouts, improving grid stability.

Energy efficiency and demand response can be complementary or competitive in terms of their impact on power system costs [4]. When energy efficiency measures significantly reduce load, it can lead to a decrease in the need for new generation, transmission, and distribution system investments, competing with the potential benefits of demand response. However, energy efficiency and demand response can complement each other by shifting load away from peak demand periods. For example, efficient lighting or HVAC systems reduce overall energy consumption while turning off non-critical equipment during high-demand periods can alleviate stress on the grid.

BENCHMARKING, RENEWABLES AND INCENTIVES

Certain commercial buildings must be mindful of benchmarking requirements, depending on location. The Clean Energy Act of 2018, for example, established requirements for certain commercial buildings to benchmark their energy and water usage using the ENERGY STAR Portfolio Management Program and report findings to their local government. There are financial penalties for non-compliance.

Agencies must meet rigorous sustainability goals, including improving energy and water efficiency, boosting the percentage of their energy use that comes from renewable electric and alternative energy, and completing broader sustainability assessments.

Benchmarking a building can lead to significant energy savings, often up to 30%, depending on the current efficiency level of the building. In the United States, Energy Star and its partners helped save over 520 billion kilowatt-hours of electricity and avoid $42 billion in energy costs in 2020 alone [5], resulting in more than 400 million metric tons of greenhouse gas emissions reduced. That was more than 5% of the country's total greenhouse gas emissions.

Without measurement, there can be no improvement. Evaluating a building's energy performance against like facilities helps identify optimization opportunities such as improving insulation, upgrading HVAC systems, and using energy-efficient lighting.

Energy companies are eager to support organizations looking to optimize their buildings: it helps them with their capacity challenges and sustainability pressures. In some cases, they will even provide no cost energy assessments or facility "walks." A best practice is for organizations to connect with their local energy company and explore the various federal and state incentives available, especially for those investing in, or looking to invest in, renewable energy. There's also a useful virtual resource in the Database of State Incentives for Renewables and Efficiency (DSIREUSA.org) to learn more about opportunities available across the U.S.

Power companies want to support renewable energy investments: there are many credits available for installing renewable energy sources, as well as renewable energy certificates which can be purchased rather than installing and maintaining new systems. Renewable energy certificates ensure that the purchased renewable energy was only used by the purchaser.

Large companies can also sign up to pay for green tariffs where a portion of the utility bill goes toward supporting renewable energy. Certificates also support the development of creating renewable energy by increasing demand for it. Finally, carbon offset credits are another option, however, in this case a company is paying for projects that reduce carbon emissions, such as planting trees, to mitigate the impact of greenhouse gases that have already been produced.

ENERGY TREASURE HUNTS

A simple way to identify energy-saving opportunities while generating more occupant buy-in for sustainability and conservation programs is through conducting energy treasure hunts. Hunts are highly recommended before engaging in complex energy-investment projects. Energy treasure hunts focus on day-to-day operational opportunities, many of which will be low- or no-cost. The hunt involves a diverse team—representing more than building managers and engineers but non-technical departments as well—who explore different parts of the building to discover opportunities to conserve energy.

Energy treasure hunts are designed to avoid the negative connotations of an "audit" and focus on identifying improvements ("hunting for treasure"). Teams are trained before the walk begins and present their findings and ideas for operational improvements to management. Involving unique perspectives and leaning on people who have day-to-day experience as an occupant of the building enhances the success of these activities. Moreover, energy treasure hunts foster team building and a strong sense of ownership and the shared success in conservation efforts.

Energy treasure hunts have produces measurable results for companies that have put them into practice. Over a 10-year period, General Electric Company has saved $110 million by implementing findings from energy treasure hunts conducted at their 300 facilities worldwide [6]. Manufacturing facilities across the country have seen savings of at least $250,000 a year and up to $500,000 per year [7] per facility after conducting energy treasure hunts.

RETRO-COMMISSIONING AND GATEWAY SOLUTIONS

Retro-commissioning (RCx) is the process of optimizing an existing building's systems and equipment to identify energy-saving opportunities and enact system-improving measures. Benefits of retro-commissioning include improved occupant comfort, reduced maintenance costs, and increased lifespan of building systems.

There are two main types of retro-commissioning:

- Virtual commissioning is a process of simulating and verifying control systems and processes for production line using virtual models before the actual commission.
- Monitoring-based commissioning is the process of using real-time monitoring data from building automation systems to commission building systems and identify operational inefficiencies. The process involves the use of a cloud-based system and advanced analytics, including machine learning and the Internet of Things (IoT).

Modern technology has made retro-commissioning and energy conservation immensely easier. For example, ESFM USA (Elevating Solutions in Facilities Management, www.esfm-usa.com) leverages a gateway system across multiple client locations (illustrated in Figure 3). The gateway is a small device that plugs directly into a facility's building automation system. Like a stethoscope, it is a listening device that collects data from equipment to be evaluated for faults, runtimes, and schedules, predetermining opportunities for efficiency in real-time.

The gateway pulls data from various devices, equipment, and systems within a facility, with options to choose what to monitor—including temperature, humidity, climate, carbon dioxide (CO_2) emissions, etc. All

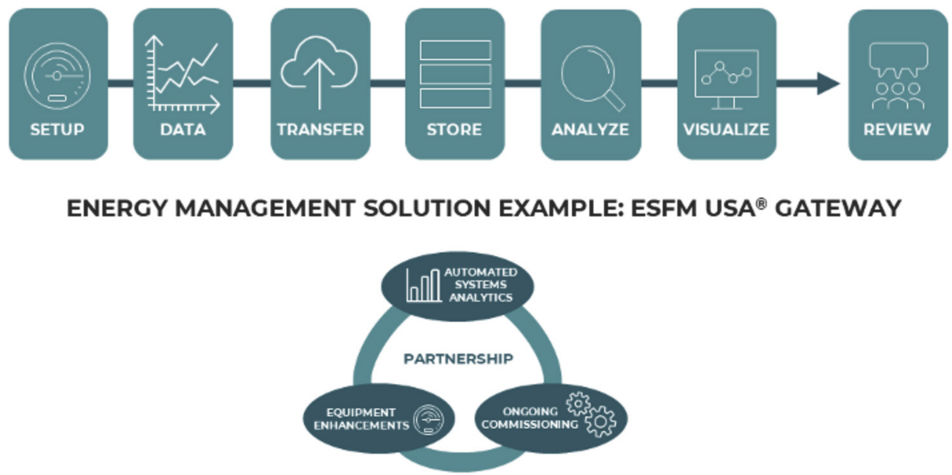

Figure 3. Illustration of ESFM's Gateway System (Source: ESFM USA)

the data is analyzed in a cloud-based system, allowing for immediate comparison with historical data, such as past utility bills and seasonal weather patterns.

ESFM USA conducted 60-day studies at three unique client locations, totaling 1.4 million square feet. By analyzing information from the gateway, the team discovered utility savings of 15 to 20% at each location.

CONCLUSION

Electricity prices are on an upward trend with no sign of decreasing. However, businesses can take steps to improve energy efficiency, which can lead to reduced utility costs.

Investing in renewable energy, such as solar or wind power, is a sound decision that not only can help with long-term cost management but also mitigate environmental impacts of fossil fuel reliance. Purchasing renewable energy certificates is a way to do this without converting systems straightaway.

Before investing in renewable energy, it is important to first improve energy efficiency of existing systems. Implementing energy saving practices such as LED lighting, upgrading to energy-efficient appliances, automated lighting with sensors, smart thermostats, and taking advantage of natural light are great places to start. Furthermore, tools such as smart meters and IoT devices can help optimize energy usage.

Take advantage of utility-sponsored energy efficiency and demand response programs, especially if they offer rebates and incentives for reducing energy use during peak demand periods.

Finally, organizations should cultivate a culture of sustainability. When people are empowered to take ownership and identify sustainability measures, they are more invested in the overall success. Establish Green Teams of employees who model and encourage environmentally responsible behaviors. Conduct collaborative and interactive Energy Treasure Hunts to identify areas of opportunity in energy management with low-cost solutions. These initiatives serve a greater purpose beyond electricity conservation and monetary savings; these culture shifts contribute to grid stability and help reduce greenhouse gas emissions, benefitting the planet.

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