Nuvalence

POWER & UTILITY

# Taming Renewable Energy Complexity with an AI Platform

WHITEPAPER

# Purpose & Audience

The Power & Utility industry is going through an extreme transformation, primarily led by the global need to shift to renewable energy.

In this white paper, we will evaluate the role that technology can play in this global energy shift. Specifically, we will propose a preliminary platform architecture employing the latest advancements in data, Machine Learning (ML), Artificial Intelligence (AI), and distributed cloud computing.

The intended audience for this paper is a C-level Power & Utility executive interested in understanding how an integrated AI platform supports their journey into multi-sided networks (i.e., OEMs, distributors, parts suppliers, farm operators) or Directors or Chief Technology Officers looking for practical guidance on the same.

# Introduction: A Unique Moment in Time

Many have proclaimed that climate change is the issue of our generation. While such discussions can quickly lapse into political discourse, almost everyone agrees that diversifying our means of energy consumption and production is a worthy goal for the global community.

Investment into renewable forms of energy is certainly not new and has already been decades in the making. We stand at a unique inflection point where two factors, in particular, have created an opportunity for accelerating outcomes. If coupled with the right technology investments, regulatory incentives, and favorable unit cost economics are poised to usher in a new era of global energy production.

### WHERE THERE'S A WILL, THERE'S A WAY

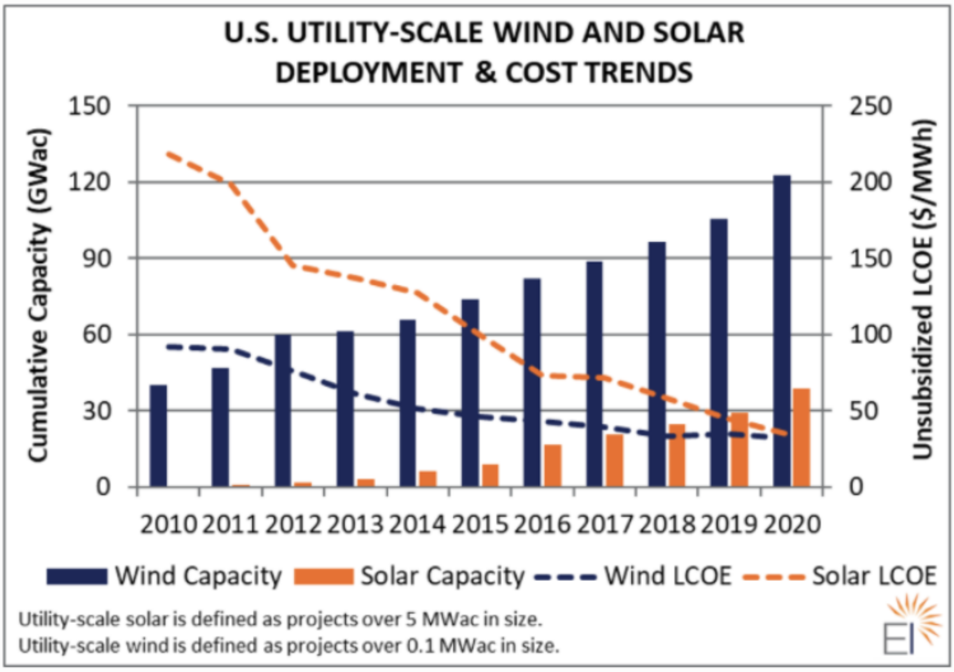
First, governments and global alliances across countries have come together to set aggressive goals for greenhouse gas emission reductions. In the United States, the Inflation Reduction Act (IRA) aims to reduce levels to 43% below 2005 levels by 2030. While such proclamations can be easily dismissed as toothless political rhetoric, the IRA backs up this goal with durable, long-term economic incentives, including transferable tax credits for investments and production. This makes prioritizing investments that help reduce greenhouse gas emissions a matter of good business.

You might ask yourself: "haven't we passed this kind of legislation before?" The answer is simple; no, we have not. This is the most transformative legislation since the Highway Act in 1956.

Previous regulatory attempts to accelerate investment in renewable energy came in fits and starts. The IRA sets aggressive commitments for the next ten years, giving stakeholders enough runway to make at-scale investments in a predictable way. Furthermore, the IRA is a rare bipartisan piece of legislation that provides political air cover to future administrations. No doubt this is also influenced by consumers becoming more aware of not only their own carbon footprint, but also the footprint of the companies they choose to do business with and the institutions they elect representatives to run.

### THE COST CURVE IS ALREADY BENDING

The second major factor creating this inflection point is that manufacturing for key methods of renewable energy production has matured significantly over the past decade. This has resulted in more competitive pricing when compared to traditional means of production. In the chart below, the term “LCOE” refers to the “Levelized Cost of Energy” and is used to estimate the cost of power over the warranted lifetime of the wind or solar system.




U.S. utility-scale wind and solar deployment and cost trends. Users are free to copy, distribute, transform, and build upon the material under the CC BY License as long as they credit Energy Innovation for the original creation and indicate if changes were made. [-] ENERGY INNOVATION, USING DATA FROM LAWRENCE BERKELEY NATIONAL LABORATORY

One consequence of reduced manufacturing costs for the equipment itself is that a greater portion of the total cost of ownership has shifted to maintaining and operating large wind and solar power plants. As we’ll explore, this creates an opportunity for technology to play an even more important role moving forward. We’ve seen this in previous maturing hardware cycles, including personal computers, smartphones, and televisions, to name a few. Eventually, the hardware reaches a unit level of economics and performance capability such that differentiation is mainly driven through software.

## Enter Technology

With regulatory and manufacturing tailwinds, the stage is set for technology to super-charge our global efforts to produce and consume cleaner energy. There is a long and storied history of technological innovation being ignited once politics and physical world dynamics stop being blockers.

The technology landscape today is uniquely suited to support a shift to renewable energy. Ubiquitous access to large-scale cloud computing and small-scale distributed mobile devices creates a fertile substrate for innovation.

To keep us grounded in reality, we will explore how technology can play a role in reducing greenhouse gas emissions using real-world examples inspired by a Nuvalence client.

## The Challenge

Our client is one of the largest manufacturers of wind turbines and solar panels on the planet. Per the chart shown earlier, they have become adept at improving the efficiency of their manufacturing processes. While they will continue to improve along this vector, they want to leverage modern technologies to differentiate competitively, leading to their introduction of software as a revenue-generating part of their business. Ultimately, their goal is to build software that even supports farms employing hardware from their competitors.

The client has asked us to look at the entire set of "user journeys" within their span of control to better understand how software can create more differentiated offerings.

## A Platform Approach to a Systems Challenge

It's important to view this challenge as a complex system of many participants, each with different motivations influencing the outcomes. As a result, any technology investment must be able to connect these stakeholders to drive adoption and avoid unintended consequences. Most importantly, each stakeholder needs to know that this system gives each stakeholder access to value. In order to ensure access to value for all, the system should be governed by two tenets: (a) ensure that each stakeholder can derive meaningful value and (b) enable each to contribute to the system such that they can increase the amount of value they and/or other stakeholders can derive. The only way to satisfy these two tenets and deal with the complexity of the system is by leveraging a platform architecture. Unlike a single-purpose application or point solution, a platform approach invites participation from an ecosystem of partners enabling decentralized innovation, value-creation, experimentation, and expansion.

The rest of this paper will:

1. Establish a coarse set of use cases that the platform should satisfy, derived from our experience with the Nuvalence client. Nuvalence, since its inception, has been guided by the intersection of architecture and product management as disciplines. These "anchor use cases" are foundational to the approach of practical platform design.

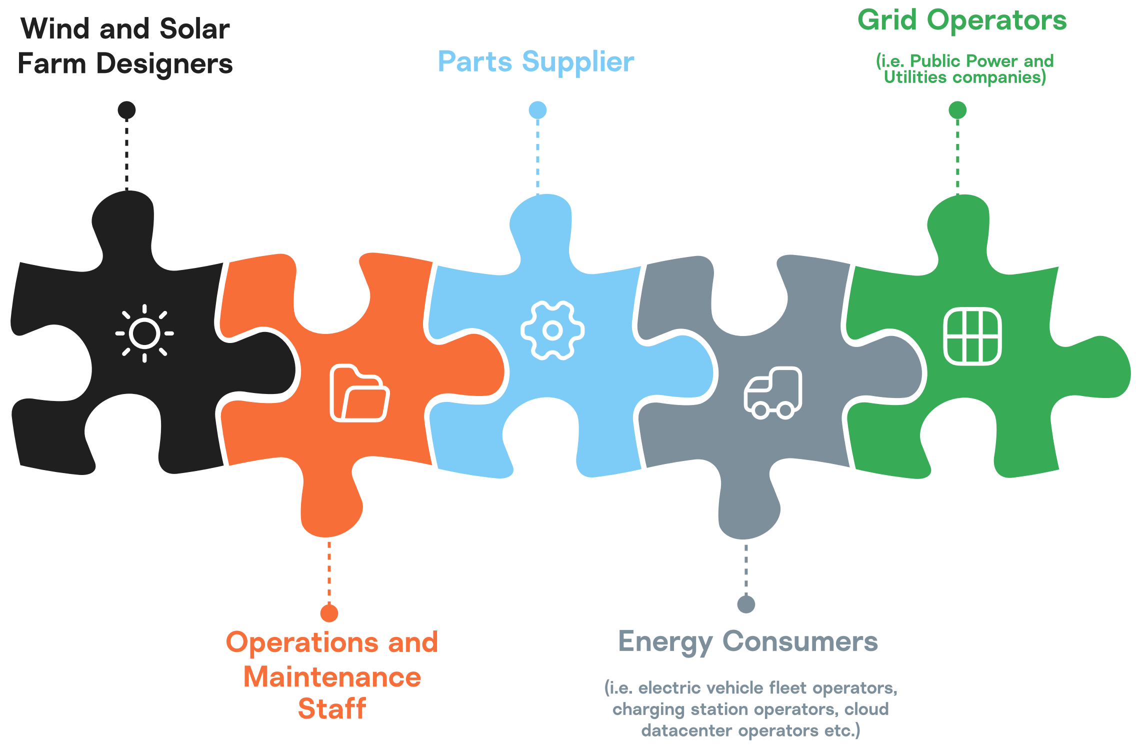
2. Demonstrate how data, AI, and ML are best suited to deal with the enormous complexity associated with these use cases.

3. Provide a bespoke platform architecture sketch to unify various subsystems, ensuring that all stakeholders benefit from the two tenets described earlier.

The output of this exercise is to provide a well-reasoned, opinionated view on the general structure and value of an AI-focused platform for the renewable energy domain; for the remainder of this paper, we'll refer to this as the **R**enewable **E**nergy **AI P**latform, or **REAP**.

## REAP Anchor Use Cases

Let's start with describing use cases. In the case of the Nuvalence client, there are several actors intimately involved in the full end-to-end use case as it relates to energy production and consumption. Each of these actors typically has their own primary use case.




| Actor | Use Case | Goal |
|---|---|---|
| **Wind and Solar Farm Designers** | Farm design and layout | Optimally configure the farm to maximize efficiency and output given geographic and other factors |
| **Operations and Maintenance Staff** | Monitor all farm devices, repair and remediate device issues | Minimize downtime, respond to anomalies, determine root cause of problems, quickly resolve issues |
| **Parts Supplier** | Ship parts to maintenance staff in response to remediation requests | Rapid delivery of parts to remediate failures and reduce downtime |
| **Grid Operators** (i.e. Public Power and Utilities companies) | Orchestrate and optimize energy distribution and storage | Provide the most cost effective means of energy delivery and storage |
| **Energy Consumers** (i.e. electric vehicle fleet operators, charging station operators, cloud datacenter operators etc.) | Consume energy efficiently with cost optimized transparency | Meet energy needs with the lowest cost possible |

Now, as a practical matter, it may make sense to pick a specific target use case and build specifically for its concerns. However, taking a platform approach is critical from an execution and delivery standpoint (this Nuvalence whitepaper provides a blueprint for accomplishing this). While we'll be using the aforementioned use cases to validate our REAP architecture, keeping a general purpose (within the bounds of this domain) mindset will help avoid building a series of incongruent point solutions that would eventually compete with each other rather than cooperating.

Let's examine each anchor use case and develop a point of view on how technology can be leveraged to meet each desired goal. For each use case, we'll summarize a "Technical Problem Statement" and "Proposed REAP Subsystem(s)" to aid in solving each problem statement.

## ACTOR: WIND AND SOLAR FARMS DESIGNERS

As the manufacturing of solar and wind systems have improved, the location, design, and layout of the farms have become increasingly critical to further improve efficiency.

Wind farm efficiency is highly dependent on complex and variable factors such as airflow, the interaction between wind turbines, material vibration dynamics for onshore versus offshore farms, local environmental impact, etc. This has been studied and optimized for some time now.

Similarly, solar farm design is a complex problem that needs to factor in the material used for the cells, solar radiation levels, temperature dynamics, air pollution levels, wind load on the cells, the orientation of the cells, etc.

Only recently has the computational power been available to run the required simulations quickly and at scale through large-scale cloud providers using high-performance computing (HPC) coupled with AI/ML capabilities. Incredibly complex models can be used to run simulations efficiently. This had previously been the exclusive domain of large academic institutions or giant corporations, but is now available at fractions of the cost to all parties. Financial services companies have long leveraged sophisticated modeling and simulations to help optimize their trading in real time. These techniques can now be efficiently applied to new domains, including renewable energy production.

- **Technical Problem Statement**: deriving siting intent from multi-factor telemetry data
- **Proposed REAP Subsystem(s)**: Environmental Telemetry (ET) Ingest, ET Analytics (primarily latent/historical), ET Batch Data Sync, Farm Site AI Modeling

As we'll see in the next use case, operational signals from running large-scale farms can be leveraged in a feedback loop to improve the ML models to create more efficient designs in the future.

### ACTOR: OPERATIONS AND MAINTENANCE STAFF

Operations and maintenance now comprise 30-45% of the TCO of wind and solar farms (per McKinsey). While "keeping the lights on" is important, it's even more critical to continuously optimize the configuration of farms and, when needed, to ensure repairs are handled quickly and proactively where possible.

In the case of the Nuvalence client, their global farms generated 55 billion discrete daily signals sent to operational staff. As you might imagine, this creates a set of significant challenges/requirements, including:

- Reliable ingestion of signals which often arrived late or out of order
- Generation of real-time dashboards with this massive amount of data
- Detection of anomalies in the data, including real-time prioritization
- Application of machine learning models to predict future failures based on signal patterns
- Long-term reporting of patterns to improve future farm design (i.e., feedback to the prior use case)

As part of this use case, we were able to reliably predict when parts in either a wind or solar device were going to fail based upon the signals. This enabled the client to proactively order parts and minimize disruption to energy generation. Consider the advantages of being able to order a replacement for a soon-to-fail solar panel in advance and apply the maintenance at night, instead of during peak-generation hours. Because of the highly dynamic and interconnected nature of this system, Recurrent Neural Networks (RNN) can be employed to create effective feedback loops both for operations and for future farm planning.

- **Technical Problem Statement**: making sense of maintenance needs and deriving failure prediction & repair intent from high-volume, high-rate, multi-factor telemetry data
- **Proposed REAP Subsystem(s)**: eQuipment Telemetry (QT) Ingest, QT Streaming Analytics, QT Predictive Maintenance Management, RNN Operations Planning

Supporting the Operations & Maintenance staff and their use case is critical for controlling costs in power distribution and reliability.

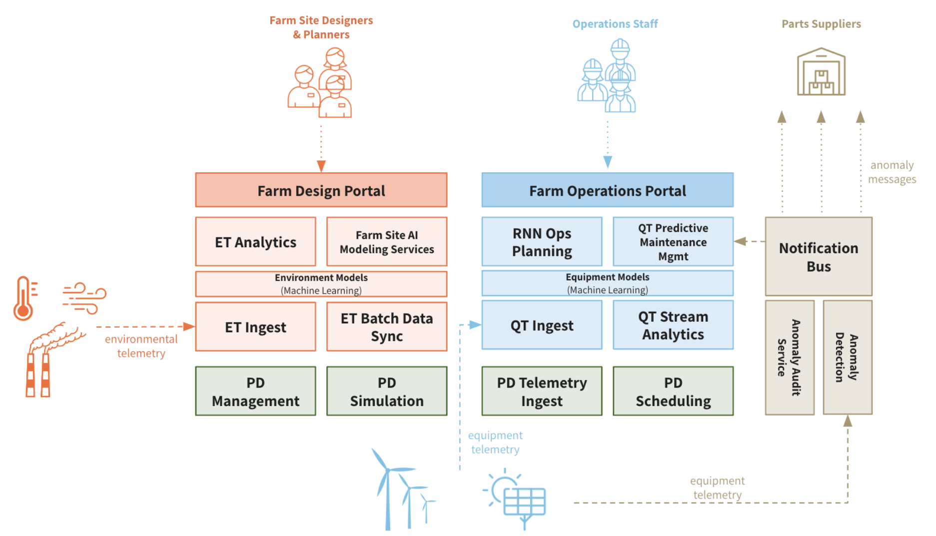
### ACTOR: PARTS SUPPLIERS

Taking a platform approach to this problem also enables parts suppliers to participate directly in this end-to-end workflow. In the previous use case, we discussed proactively identifying future failures and ordering parts in advance. Building an observability stack within REAP enables one or more parts suppliers to integrate into the system directly.

For example, using ML, when a part is predicted to fail and needs replacement, parts suppliers can be notified directly from the observability platform, prompting them to fulfill and ship the order. The operations and maintenance staff can confirm and track the order to prepare for maintenance in a suitable and optimal manner.

- **Technical Problem Statement**: provide external parties with either/both real-time access to anomalies and other events, or receive triggered notifications of the same
- **Proposed REAP Subsystem(s)**: ML-based Anomaly Detection, Multi-tenant Event Notification/Data Access, Write-Once, Read Many (WORM) Audit Access, Secure Publish/Subscribe

Aside from parts suppliers, there are usually other participants in this workflow. For example, it is often a regulatory requirement to share some portions of the data collected with government agencies. From a technological point of view, this means that the system needs to be designed in a multi-tenant manner with simple, reliable, and secure APIs. This allows ecosystem participants such as the parts suppliers or regulatory bodies to seamlessly "plug in," getting access only to the portions of the system and data relevant to them.




## ACTOR: GRID OPERATORS

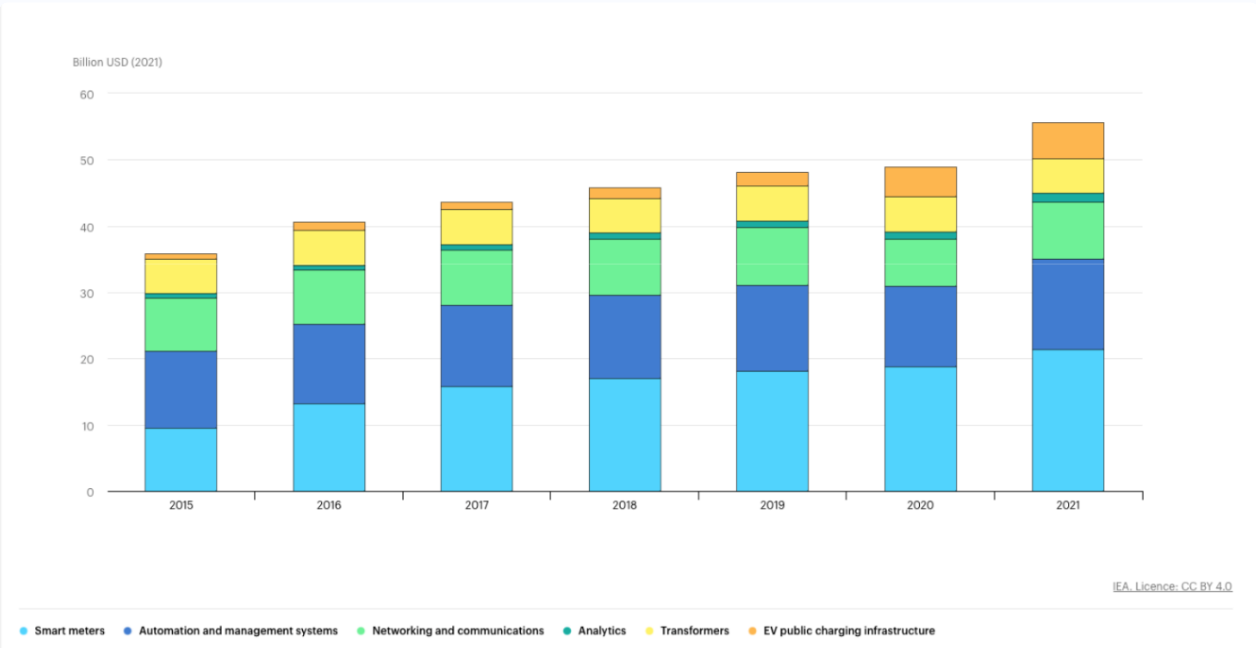
Volumes could and have been written about the need to modernize our power grids. We won't rehash those here; most would argue that our current grid system is still in need of further modernization. What is important to call out is that technology plays an even more important role when we consider adding renewables to the grid, because the orchestration and optimization challenges become even harder. This is due to the fact that energy generation becomes more distributed, variable, and harder to predict. Anyone who has depended on a weather forecast for personal planning purposes can certainly relate!

Variability in generation dynamics makes energy storage more important as well. We'll need efficient ways to store energy when production is abundant, and consume from the storage when it is scarce. While advancements in battery and other storage technologies have advanced, we are still orders of magnitude behind what is needed to power a large city for even one full day. The vast majority of electricity storage worldwide is managed with pumped hydro storage (PHS), a decidedly low-tech solution. Water is pumped to a higher elevation when electricity is plentiful (e.g., daytime for solar) and released to drive turbines creating electricity when needed.

In addition to being more variable, renewable energy generation also promises to become more distributed and decentralized over time, in large part due to the economic incentives in the IRA. This makes the trade of energy between grid participants more dynamic if the technology is in place to support it. This is already happening today, as homeowners with solar panels can take from and contribute to grid capacity.

Smart grid efforts enable energy consumers to communicate more actively and share data with energy providers using new sensors and standards. This will explode in the coming decades as the relationship and feedback loop between these parties becomes a more real-time closed-loop system. It will make processing 55 billion signals a day from wind and solar farms seem quaint by comparison. Everything from smart cities to smart appliances will be involved in optimizing our energy production and usage.

**Investment in Digital Infrastructure in Transmission and Distribution of Electricity Grids**




IEA, Investment in digital infrastructure in transmission and distribution electricity grids, IEA, Paris https://www.iea.org/data-and-statistics/charts/investment-in-digital-infrastructure-in-transmission-and-distribution-electricity-grids, IEA. Licence: CC BY 4.0

With variable generation patterns, relatively expensive storage, and a massive flow of signals across a highly distributed network, it's obvious that technology and ML/AI, in particular, will need to play a major role if we are to maximize the benefits of renewable energy sources. If you're a software engineer, you might recognize this challenge as a distributed large-scale scheduling and network routing problem for the physical world. What we need is an Energy Operating System (EnergyOS).

Given a set of constraints, goals, and input data, modern computing and ML/AI technologies can be applied to these types of challenges. REAP would need to keep pace and remain architecturally consistent to support these use cases.

- **Technical Problem Statement**: ensure reliable, highly optimized power distribution in the context of decentralized, yet aggregated, unreliable power sources
- **Proposed REAP Subsystem(s)**: Power Distribution (PD) Management, PD Simulation, Real Time PD Telemetry Ingest, PD Scheduling

Once again, a platform approach allowing data consumers and producers to connect modularly will be critical.

## ACTOR: ENERGY CONSUMERS

Consumers have been taking a more active role in their own energy consumption patterns in large part due to their awareness of its impact economically, environmentally, and geopolitically. They are also becoming more comfortable changing their habits and practices as they relate to electricity usage (load shifting as a result of reduced electricity prices at night versus peak day) and transportation modes, including electric vehicles (the rebates and tax breaks don't hurt here either!).

Residential solar usage has grown over 20% per year for several years, and promises to accelerate with new IRA incentives. This has led to commercial development for residential batteries for energy storage, and EV manufacturers are even enabling consumer vehicle batteries to serve as a home generator for emergency backup power. Given the variability in cost and availability of renewable energy, there are countless ways technology can play a role in optimizing consumption, particularly with sensors and telemetry tied to most devices. "Smart Thermostats" are really the tip of the iceberg.

- **Load Shifting** - When consumers have some flexibility on when to consume energy (hot water heaters, washers/dryers, electric vehicles, dishwashers), these devices can automatically operate in periods when electricity is less expensive.
- **Orchestration** - If a neighborhood staggers its energy consumption, this "flattens the curve" and reduces expensive surge situations on the grid.
- **Energy Analytics** - If consumers were able to better understand (in plain english) and measure the results of making their homes more energy efficient with sensors and scoring, it could accelerate changes.

In addition to individual consumers, operators of vehicle fleets, vehicle charging networks, real-estate landlords, and cloud data center operators consume energy at scales that make active participation in the production/consumption cycle even more critical. They already actively manage load shifting, orchestration, and efficiency measurement, but often do so with antiquated tools that do not operate in real-time and do not produce actionable insights. With all of the telemetry and signals coming from these new “smart” devices, REAP could provide critical actionable insight that can change the game. Currently, much of this data is captured in disparate systems in formats that make it difficult to find real insight. Creating data-driven application programming interfaces (APIs) and effective federation mechanisms while ensuring security and privacy is the right way to move forward.

It’s clear that to accomplish any of these goals, technological innovation will need to be front and center. By stepping through each anchor use case in detail, we have demonstrated why a platform approach is now obvious and absolutely necessary for success. If consumers of energy cannot actively participate and get insight from the production process, the system can never be optimized.

# Conclusion

Renewable energy promises to dramatically change how the world produces and consumes energy. Technology will be front and center supporting this transformation.

- AI/ML and distributed platforms will play a key role in realizing and optimizing the benefits.
- The massive onslaught of data from devices combined with the variability dynamics at play with renewables lends itself well to AI/ML use cases.
- The wide spectrum of actors and their use cases makes taking a platform approach the only sensible option for delivery of this technology.

This does not mean that a single technology or vendor needs to build everything themselves. On the contrary, platforms enable decentralized innovation in a coordinated manner so that all ecosystem participants can add and extract value pursuant to their own needs.

While this paper has focused on renewable energy production and consumption, the proposed approach can be applied to many industries in the environmental space. For example, most governments and corporations set "Net zero" goals as part of their long-range plans for decarbonization; this requires emerging technologies to be developed and implemented for carbon capture which opens an entirely new set of challenges and opportunities. We’re really only beginning to scratch the surface of what is possible. The coming decade will be an exciting one for the intersection of technology and energy.

*While the focus of this paper was on renewable energy, it’s not hard to extrapolate many of the use cases and challenges to more traditional means of energy production. Indeed, only about 20% of the world’s total energy consumption comes from electricity. This means that even if we were able to fully generate this from renewables, 80% remains based on other sources. While renewable energy will play a larger role in our global economy, existing energy sources are not going anywhere and will continue to play a key role. This diversifies our production and consumption options, but the added complexity must be met with critical technology investments across that value chain.*

Let's talk about how an integrated AI platform can support your journey into multi-sided networks.

GET IN TOUCH

## ABOUT NUVALENCE

Nuvalence is a next-generation consulting firm specializing in mission-critical, intelligent platforms for the world's most ambitious organizations.

Using our product-driven, AI-centric approach, we empower organizations to build for the intelligent digital future. Our elite team of product leaders, data scientists, designers, and software engineers enables our clients to solve their most complex technology product challenges and positively impact people and the world.

We don't just deliver software, we deliver outcomes.