

R&D WHITE PAPER

24/7 Carbon-Free Energy Trends, Opportunities and Solutions

This White Paper published by EDF R&D, the Research and Development division of French utility EDF (Electricité de France), presents the main challenges and innovative solutions in the 24/7 Carbon-Free Energy (24/7 CFE) topic.

This White Paper is intended to share R&D insights on granular energy matching concept with EDF partners: electric utilities across the world, grid operators, renewables developers, along with international financing institutions, commercial or industrial clients and public agencies in the energy sector.

This document introduces four main domains linked to granular energy matching and 24/7 CFE solutions, illustrated by recent EDF works, R&D solutions and references.

Granular matching concept can play a role to advance decarbonization

Combat issues in EACs and mitigate price risks in PPAs

Drivers for granular matching concept

Today, corporations have different approaches to address their use of carbon-based energy. These efforts have mainly focused on procuring renewable electricity resources through power purchase agreements (PPAs) and unbundled Guarantees of Origin (GOs) in Europe and Renewable Energy Certificates (RECs) in the US (hereinafter collectively referred to as Energy Attribute Certificates (EACs)).

Typically, corporates use the procured EACs to reduce their corporate “Scope 2” GHG emissions based on existing voluntary GHG accounting practices. However, critics of this approach argue that the energy output profile of contracted renewable resources (or EACs) may not match a customers’ hourly consumption on a 24/7 basis. Additionally, unbundled EACs may be associated with renewable energy generated in a bidding zone or grid that is geographically different from where the contracted electricity is consumed.

Corporates are also increasingly exposed to market price fluctuations, especially during periods of low renewable production when market prices often spike. This is accentuated by high penetration of variable renewable energy. Current 100% renewable PPAs (pay-as-produced and baseload power purchase agreements) do not fully hedge price volatility risk as the offtaker

is liable for complementing its PPA purchase from the market at periods of under-supply. While corporates can hedge price risk through commodity markets (e.g., Contract for Difference, futures, forwards, swaps or options), not all products address the decarbonization issue.

In response to growing concerns about the potential mismatch between renewable energy procurement and end-use energy consumption, as well as price risks, some large corporate energy buyers began to procure “time-matched” renewable energy and 24/7 carbon-free energy (24/7 CFE). The 24/7 CFE concept was first introduced by Google in 2018 and aims to always match each Google facility with carbon-free power around the clock (also known as 24/7 CFE).

Since then, the granular matching concept has been gaining momentum in the world. Currently, there is a vibrant 24/7 CFE ecosystem with a growing number of stakeholders participating across all segments of the value chain, from authorities, standardization bodies, issuing bodies to technology providers. Some of the leading organizations that are shaping the development of 24/7 CFE concept include UN 24/7 CFE Compact, GHG Protocol, Eurelectric, EnergyTag, RE100, as well as the European directives which define Guarantees of Origin. In particular, EnergyTag is actively

engaging the International Standards Organization (ISO) and International Electrotechnical Commission (IEC) to develop 24/7 CFE standards.

Besides voluntary efforts from market players, governments and regulators are introducing granular energy matching into new regulations.

Shifts to granular matching driven by increasing regulatory pressure

The US introduced tax incentive – IRA 45V (also known as the “Clean Hydrogen Production Credit”) in 2022 to promote the production of clean hydrogen. It consists of three pillars (which are aligned with the 24/7 CFE principles): Incrementality, Deliverability and Temporality. Hydrogen producers will have to meet the above pillars by 2028 to qualify for the tax incentive. Similarly, the European Commission’s Delegated Act for renewable hydrogen will require that grid-connected electrolyzers match their electricity consumption with renewable energy produced on the same bidding zone and in the same hour, starting 2030.

Examples of multiple stakeholders in the 24/7 CFE ecosystem



Source: EDF R&D

Practical challenges in implementing granular matching concept

Limited expertise and high cost of implementation

Evaluation of the economics of granular matching solutions

To gain further clarity on the global demand for granular matching solutions, EDF conducted market studies in 2024 for the US, UK, Europe and APAC markets through interviews with tech companies, solution providers and utility companies. The results of the studies showed that energy consumers' sentiments toward granular matching varied widely across the markets.

The US market is developing more quickly with respect to the maturity of granular matching market players and registries. In the US, registries are already offering time-stamped granular certificates, supported by robust trading platforms developed by LevelTen, Quintrace and M-RETs. Market players like Cleartrace, Flexidao and Powerledger have dedicated services to support electricity customers in optimizing their purchases considering their specifications (e.g., 80% CFE hourly).

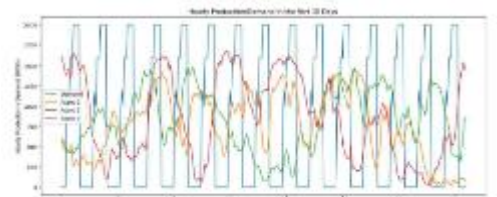
In the UK, most industry stakeholders believe that the current Renewable Energy Guarantees of Origin (REGO) Scheme, which is based on annual matching, is inadequate. Some UK companies are voluntarily seeking clean energy solutions that match their energy consumption on a 24/7 basis, especially large companies with intensive energy usage and sustainability commitments.

Despite the maturity of the granular matching markets and ecosystems in the US and UK, the granular energy matching concept remains voluntary and is mainly led by the big tech companies (e.g., Google). The key limitations to the adoption of granular matching solutions include implementation challenges and costs.

To implement granular energy matching, companies need to understand their electricity consumption and work with energy suppliers. This can be challenging for companies with small in-house energy procurement teams with limited expertise in energy procurement.

Generally, matching consumption at high temporal granularity requires more costly investments in clean technology during the hardest-to-abate periods. In 2023, EDF R&D, in collaboration with Paris Dauphine University and National University of Singapore, established a pricing model of RECs based on different time matching granularity, as well as varying matching CFE levels of low-carbon electricity. Under specific conditions, a 100% hourly-matching (24/7) PPA contract based on wind, solar and battery storage has a cost premium of 40% higher than 100% annual-matching PPA. The study also found that cost premium increases rapidly as hourly CFE matching goes above 95%.

Price modelling of the Time-Stamped REC by EDF R&D, Paris Dauphine University and National University of Singapore



Example of the result from an EDF R&D tool - matching of hourly production vs. hourly demand at a certain CFE matching level

GHG Protocol Scope 2 Revision



The GHG Protocol is now working on a revision of its Scope 2 guidance. GHG Protocol anticipates releasing draft standards for public consultation in 2025 and publishing final standards in the latter half of 2026. Following topics are under discussion.

- Maintain dual reporting requirement (location- and market-based) vs. single reporting
- Granular vs. broad data and quality criteria requirements:
 - Time matching: Annual vs. hourly or sub-hourly
 - Location matching: Market boundaries vs. bidding zones
 - Additionality*: Mandatory or not

*Refers to the requirement that CFE procurement leads to the development of new renewable energy capacity that would not have occurred otherwise.

How to provide reliable and affordable 24/7 CFE matching

Reduce cost of offering 24/7 CFE matching through diversification, aggregation and optimization of generation assets

Develop innovative 24/7 CFE solutions and services

Despite the implementation and cost challenges of granular energy matching, by more accurately matching electricity demand with CFE, large energy users are less susceptible to being accused of greenwashing and could unlock new sources of capital, such as sustainable loan.

The key question is whether energy suppliers are able to address these challenges, and offer reliable and affordable hourly CFE matching products and services. Given the growing global momentum of 24/7 CFE matching, EDF businesses have been looking into new business opportunities in this space, as well as developing new 24/7 CFE PPAs in their respective market segments.

Studies done by EDF R&D found that large utility companies like EDF, could offer reliable and affordable 24/7 CFE products and services through the following approaches.

1. Diversification of generation assets: Deploying a large portfolio of low-carbon generation technologies for deployment (e.g., solar, wind, bioenergy, hydropower, nuclear, etc.) can lower the cost premium of supplying 24/7 CFE by leveraging the complementary strengths of each source.

2. Added value for storage: Storage assets, like Battery Energy Storage System (BESS), play an important role in achieving 95%~100% hourly CFE matching. With varying price signals across different time periods, investments in storage technologies can be incentivized.

3. Demand pools: Ability to manage contracts with multiple energy consumers and aggregate their load profiles increases flexibility and potential to achieve higher CFE matching levels.

4. Benefits from natural hedging: Volume and price risks from intermittent renewable energy sources can be mitigated by aggregating multiple renewable assets of various natures (e.g., wind, solar PV, hydropower, etc.).

5. Optimized aggregations: Advanced optimization algorithm to select the lowest cost asset combinations, with the highest hourly CFE matching based on customer's load profile.

6. Excess CFE for grid services: Excess CFE could participate in electricity markets and gain additional revenues

through market arbitrage, and provision of grid balancing services, frequency regulation, etc. This could result in reduced cost premium for 24/7 CFE buyers.

7. Incentives and Subsidies: Access to additional government incentives, subsidies, and tax benefits for granular energy matching projects.

EDF UK and JPMorgan Chase collaborate to power with 100% renewable energy in real time



In November 2021, JPMorgan Chase and EDF, in partnership with Cleartrace, announced a collaboration to help power JPMorgan Chase's UK offices with 100% renewable electricity. JPMorgan Chase's electricity consumption was **matched to renewable generation on a 24/7 basis**. Matching takes place on a half-hourly basis, through source-specific access to EDF's 8 TWh of Power Purchase Agreement (PPA) portfolio. This is the first bespoke agreement in the UK to enable organizations to take a real-time view of their energy sourcing and associated carbon footprint.

How to develop end-to-end 24/7 CFE solutions and services

24/7 CFE PPA contract design and real time asset management

Develop innovative 24/7 CFE solutions and services

EDF R&D is supporting EDF businesses in the development of end-to-end 24/7 CFE products and services for energy intensive industries.

- **Affordable and reliable 24/7 CFE PPA:** In 2024, EDF R&D developed a proprietary optimization algorithm which can construct optimum PPA contracts by minimizing the overall cost and offering the most competitive PPA price to customers. The algorithm aggregates multiple renewable production assets to match the customer's load curve based on customer's desired matching level and preferred generation assets.
- **Real-time monitoring:** In 2024 Paris Olympics Games, EDF acquired technological advancement and built capability in tracking low-carbon electricity consumption and generation through the development of real-time tracking software – Trackelec.

EDF R&D has successfully demonstrated the deployment of 24/7 CFE solutions. To accurately quantify the energy loss in the charging and discharging of batteries, EDF R&D developed and tested the time-stamped REC accounting methodologies using the EDF MASERA multi-energy testbed in Singapore.

Going forward, the demand for data center usage has surged.

Data centers could potentially account for 13% of worldwide electricity demand by 2030, leading to a substantial increase in electricity consumption to power these facilities that could now reach hundreds of megawatts and even the gigawatt scale. This escalating demand for energy raises concerns about carbon emissions and the environmental impact. To reduce carbon footprint and initiate a move to 24/7 CFE, data centers could evaluate various carbon-free energy technologies, especially supply from advanced clean technologies. 24/7 CFE aims for data centers to run entirely on carbon-free energy at all times, rather than offsetting fossil fuel use with RECs *ex-post*. As shown

MASERA at EDF R&D Lab



Leveraging its MASERA multi-energy testbed in Singapore, EDF R&D will demonstrate the certification and tracking of time-stamped RECs (e.g. TS-RECs). The key objective of the study is to define a logic for the issuance of TS-RECs (e.g., battery, Pumped Storage Hydropower, hydrogen, etc.) after storage that is accepted by certification bodies. This demonstration will enhance EDF's technical expertise and knowledge of its 24/7 CFE solutions. The capabilities developed on MASERA are expected to be applied in other countries.

in an EDF R&D study, cost premium to achieve 24/7 CFE could be reduced if clean dispatchable technologies like nuclear energy, hydro and advanced geothermal are available. Furthermore, by integrating space-time load-shifting flexibility with 24/7 CFE procurement, data centers may achieve more efficient and affordable 24/7 CFE matching. EDF R&D is developing bespoke solutions for data centers by co-optimizing flexible load-shifting capability and 24/7 CFE supply.

EDF guaranteed 100% Renewable Electricity to support Olympic Games 2024

EDF was the official supplier of renewable electricity to Paris 2024 Olympic Games. As part of its partnership with Paris 2024, EDF made a historic commitment for an event of this magnitude, to supply 100% renewable energy to Olympic games' sites across France.

In order to guarantee 100% of energy consumption was supplied by 100% renewable electricity, EDF developed **Trackelec**, an **electricity tracking tool** able to monitor hour by hour the matching between the Olympics games sites' energy consumption with the renewable energy generation from EDF's renewable energy farms.



Digital platform to track the hour-by-hour the concomitance between consumption and the production of the renewable energies.

How to promote 24/7 CFE matching

Standardized understanding of granular energy matching

Further questions that require clarity

The granular energy matching concept is gaining recognition but there is still much work to be done to achieve a standardized understanding of the concept. On this front, EDF R&D is engaging various international standards organizations and government regulators to seek clarity on the following critical questions:

1. Definition of Carbon-Free Energy:

Should “carbon-free energy” be technology-neutral? Should the definition of “carbon-free energy” align to the definition of “low-carbon generation” defined in the EU Taxonomy? If so, how should the lifecycle emissions threshold for “carbon-free energy” be determined? There is also a lack of incentive for flexibility solutions that support 24/7 CFE such as energy storage and demand-side response. Should electricity generated from all renewable energy sources be treated as carbon-free energy by default regardless of their actual lifecycle emissions?

2. System-level benefits/drawbacks:

Does 24/7 CFE truly contribute to system-level GHG emissions reduction and reduce the market risk for corporates? What is the underlying intention of 24/7 CFE’s advocates, such as Google and Microsoft, in pushing for 24/7 CFE? What are the key drivers that might push 24/7 CFE to a tipping point? How will 24/7 CFE

interact with government policies (e.g., EU Renewable Energy Directive (RED) and EU Clean Hydrogen Regulation) and major global reporting framework and policies (e.g., SBTi, GHG Protocol, RE100)?

3. Time granularity:

What is a suitable time window for CFE to match the load? Historically, RECs have been issued in batches on an annual, quarterly, and monthly basis. While hourly settlement periods are the most common time steps across markets, some markets have introduced shorter settlement periods (e.g., 15 and 5 minutes in Europe and Australia respectively). While smaller time steps could suit markets with shorter settlement periods better, it may over-constrain the solution space and reduce market liquidity. It could also pose a challenge to existing supporting IT infrastructure (e.g., information collection, computing, management). On the other hand, bigger time steps could increase market liquidity, allowing slower ramp-up technologies to participate in the market.

4. Geographical granularity:

How stringent should the market boundary be, whether interconnected power systems can be applied? Should bidding zone be used since EACs are market-based mechanisms? It may not be possible to impose

physical delivery of CFE supply to the load in all markets as it can constrain market liquidity. What should be a reasonable geographical boundary in larger markets like the US, Europe, Australia, etc.? Should energy losses be allocated if the generation is connected to the same grid as the load, but they are very far apart?

5. Additionality:

Is it appropriate to impose additionality requirement on 24/7 CFE concept? The concept of additionality is not inherently imposed on EACs. Currently, major government regulations and standards bodies (e.g., GHG Protocol, EU REDIII) are debating the need to impose additionality requirements on EACs. On one hand, additionality requirements could also pose a barrier to rapid scale up of new clean energy capacity required for 24/7 reliable CFE supply due to transmission constraints. In the US, there is a “years-long” interconnection queue to connect new clean energy projects to the grid. This queue has grown significantly in recent years, catalyzed by the Inflation Reduction Act. On the other hand, without additionality requirement, will 24/7 CFE truly drive new capacity investment, or will it simply be a reallocation of existing EACs?

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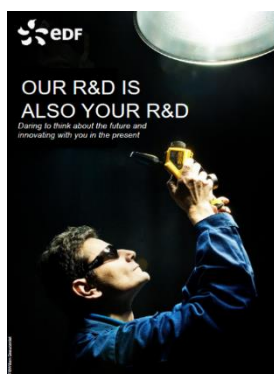
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OUR 5 SCIENTIFIC PRIORITIES

- ① **HELPING OUR CUSTOMERS REDUCE THEIR CARBON FOOTPRINT**
- ② **GENERATING MORE LOW-CARBON ELECTRICITY WITH NUCLEAR AND RENEWABLES**
- ③ **DEVELOPING POWER GRIDS TO SUPPORT THE ENERGY TRANSITION**
- ④ **DEVELOPING FLEXIBILITY SOLUTIONS TO MEET POWER SYSTEM NEEDS**
- ⑤ **ACCELERATING THE DIGITAL TRANSFORMATION**



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