OPEN PROTOCOL SPECIFICATION

OpenCEC 0.1

Open protocols for Citizen Energy Communities

Working specification for an open protocol layer that separates physical grid infrastructure, open coordination protocols, and service provision within Citizen Energy Communities.

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Scientific working draft for discussion, review, and extension.

1. OpenCEC 0.1

Working specification for an open protocol layer for Citizen Energy Communities.

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2. Executive Summary

OpenCEC is an open specification project for `Citizen Energy Communities` (`CECs`). Its purpose is not to create yet another electricity supplier model. Its purpose is to define a public coordination layer through which local energy communities can allocate energy, discover prices, exchange operational messages, and remain interoperable without being locked into a single vendor, operator, or financial intermediary.

The starting point of this document is simple. European law has opened a political and legal space for energy communities, but this space is still weakly instrumented. In many Member States, and especially in France, the legal possibility exists, yet the practical implementation remains fragmented, slow, opaque, or too dependent on bespoke arrangements. Municipalities, associations, grid operators, project developers, and service providers may all act in good faith, but the common technical and economic language needed to scale `CECs` is still missing.

OpenCEC is proposed as that missing layer.

Its logic is comparable to the role played by Internet standards. The Internet scaled because infrastructure, protocols, and services became separable. OpenCEC applies the same idea to energy communities, while adding an explicit economic dimension. The objective is not only to exchange data, but also to make the economics of local electricity coordination visible, auditable, and democratically discussable.

This matters because a real `CEC` is not equivalent to a conventional electricity supplier. A supplier mainly commercializes electricity through contracts and centralized market arrangements. A `CEC`, in the OpenCEC sense, organizes cooperation among local actors who may produce, consume, store, forecast, invest, and govern together. That cooperation requires shared rules for allocation, pricing, transparency, accountability, and local value distribution.

The present draft therefore proposes a first coherent architecture for a European-grade open standard. Version `0.1-draft v3` also separates binding profiles from explanatory, research, and future-work material, so that a political objective is not mistaken for a technical guarantee and an experimental implementation is not mistaken for certification.

The core proposal of `OpenCEC 0.1` is structured around several principles.

- The physical grid, the coordination protocol, and the service layer should remain distinguishable.
- Volume allocation and price discovery should be treated as separate but interoperable functions.
- The economic logic of a `CEC` should remain transparent and auditable.
- Service remuneration may exist, but it should remain explicit and should not be hidden inside opaque resale margins.
- The protocol should remain implementation-neutral, vendor-neutral, and open to competing algorithms under common public constraints.

The specification adopts the CLAIRE three-stage allocation model. First, each legal entity's production is assigned to its own consumer delivery points through level-`0` self-consumption. Second, every residual production volume enters one collective reservoir. Third, the reservoir is assigned through public water filling to dated consumer families in their declared priority order. This preserves the level-`0` relationship while preventing hidden producer–consumer preferences after mutualisation.

The specification also insists on the four dimensions of electricity price that should be recognized inside a serious `CEC` model:

- `volume`;
- `balance`;
- `network`;

- `forecast`.

This four-dimensional view is essential. It makes visible what is too often obscured when electricity is treated as if it were only a quantity to be bought and sold. In reality, the value of electricity depends not only on kilowatt-hours, but also on local simultaneity, system equilibrium, network constraints, and predictability. A community that ignores these dimensions risks reproducing a simplified commercial fiction rather than building a robust coordination system.

OpenCEC also draws a firm line against two major forms of drift.

The first is `greenwashing`. Terms such as `green`, `local`, `citizen`, `sharing`, and `democracy` should not be used as promotional language without operational substance. In an OpenCEC perspective, such words must correspond to verifiable rights, measurable economic effects, explicit governance mechanisms, and concrete value visible in the participating citizen's financial reality.

The second is financial drift. The document rejects architectures that replace real physical assets and understandable local cooperation with opaque financial products, speculative effects, excessive intermediation, inaccessible entry tickets, or contractual complexity that deprives citizens of real agency. OpenCEC is oriented toward tangible infrastructures, explicit rules, and progressive investment pathways, including small ground-mounted photovoltaic systems with or without batteries when they support resilient and stepwise community development.

The document is also designed to be European by construction. Most of the specification is written as country-agnostic core logic. National specificities are gathered in dedicated country sections, which may evolve as legal frameworks, perimeter rules, grid practices, and institutional interpretations change. This structure is intended to let the core standard remain portable across Member States while still taking national realities seriously.

For that reason, OpenCEC `0.1` should be read as a working draft rather than a closed doctrine. It is substantial enough to be discussed, challenged, simulated, and partially implemented, but it is not presented as final. The target proposed in this version is to progress through review, external contribution, and benchmark hardening toward a stabilized `OpenCEC 1.0` in `2027`, ideally to be fixed during a dedicated workshop in the `Ubaye Valley` in France, organized by `Soleil et Montagne` and `Aix-Marseille Universite`.

The review strategy is deliberately broad. The specification should be challenged by citizen-energy practitioners, municipalities, researchers, DSOs, TSOs, regulators, public-interest digital-infrastructure communities, and European laboratories working on power systems, smart grids, local markets, community energy, and governance. The objective is not artificial consensus. It is to make the standard more rigorous, more interoperable, and harder to capture.

In practical terms, this document aims to support at least seven immediate outcomes:

- a clearer public definition of what a genuine `CEC` is;
- a common vocabulary for technical and economic coordination;
- more reproducible local implementations;
- benchmarkable and comparable allocation and pricing algorithms;
- reduced dependence on proprietary black boxes;
- better conditions for research, pilot projects, and European cooperation;
- a future compliance and certification path for actors claiming OpenCEC compatibility.

OpenCEC is therefore not only a technical draft. It is a proposal for making the organization of local electricity more legible, more open, more democratic, and more resistant to capture. If the Internet needed open protocols to scale communication, European `CECs` may need open protocols to scale cooperation.

3. Document Status, Normative Convention, and Legal Boundary

This document is a working specification. It is not an electricity-supply licence, a grid-code substitute, a legal opinion, a consumer contract, or an authorization by a regulator, a DSO, a TSO, or a settlement operator. Applicable European, national, regional, contractual, and grid-operator rules prevail over OpenCEC whenever they conflict.

3.1. Content classes

Every substantive provision in OpenCEC 0.1 is read according to one of the following classes. A class is part of the meaning of the provision; it is not a typographic decoration.

- **NORMATIVE** provisions use the RFC 2119 keywords and define a conformance obligation.
- **INFORMATIVE** provisions explain context, rationale, comparison, or interpretation and do not define conformance.
- **EXAMPLE** provisions illustrate a rule and never override it.
- **RESEARCH** provisions identify a hypothesis, target, or evaluation question. They are not a promise of outcome.
- **FUTURE WORK** provisions deliberately defer a design decision to a later version.
- **NATIONAL PROFILE** provisions apply only when the named jurisdiction, settlement interface, and legal assumptions apply.

Unless a chapter explicitly says otherwise, descriptive and argumentative prose is **INFORMATIVE**. A sentence using `MUST`, `MUST NOT`, `SHOULD`, or `MAY` is **NORMATIVE**. Annex I is wholly normative for `CLAIRE-1.0`; Annex H is a normative operational profile where it uses those terms; Annexes A, C, F, G, and K are informative unless a sentence explicitly declares another class.

3.2. Profiles and truthful conformance claims

OpenCEC uses named profiles rather than a vague all-or-nothing claim. The profiles in this draft are:

- `OpenCEC-Core-0.1`: public rules, explicit service remuneration, replayable records, exportability, replaceability, and semantic integrity;
- `CLAIRE-1.0`: the normative per-interval volume-allocation profile;
- `MQTT-Transport-0.1`: the current message-transport profile;
- `SIGL-Authorization-0.1`: protected human management actions and authorization evidence;
- `ACC-Roaming-Experimental-0.1`: an experimental mobility scenario, not a production interoperability certification;
- `FR-ACC-Key-Adapter-0.1`: a national adapter only when its external settlement assumptions are demonstrated current and applicable.

An implementation may claim a profile only if it passes every mandatory requirement and published test for that exact profile version. It must publish the profile list, implementation version, test-suite version, test date, exceptions, and contact for security reports. `OpenCEC aligned`, `OpenCEC inspired`, and similar language must not be used to imply conformance.

3.3. Release provenance

Every official distribution must include a machine-readable and human-readable manifest containing: document version, sub-version, source commit, build tool version, source and PDF hashes, build time, profile versions, known limitations, and a changelog from the preceding distribution. `Baseline` identifies a historical comparison point; it must never be confused with the source commit used to build the distributed file.

3.4. Interpretation and dispute hierarchy

For an implementation dispute, the following order applies: applicable law and binding grid or settlement rules; the community's valid constitutional and contractual rules; the named OpenCEC profile; the profile test suite; then informative rationale. No implementation may use an informative paragraph, commercial contract, forecast, price signal, or operational convenience to silently change a completed CLAIRE allocation.

4. Foreword

Citizen Energy Communities are not, first and foremost, a technical object. They are the expression of a deeper transformation: an electricity system long conceived as vertical, centralized, and planned at large scale is now confronted with the rise of local actors able to produce, consume, store, control, and cooperate.

The European framework has recognized this transformation. By establishing the possibility for citizens, municipalities, and other local actors to organize themselves within energy communities, it opened a new institutional space. That space does not merely call for new contracts or new commercial offers. It calls for a new capacity for organization.

In France, this evolution meets an electricity structure of great historical solidity. The French system was built around institutions, operators, tariff mechanisms, and public responsibilities that pursued other objectives: security of supply, territorial equalization, grid quality, national steering, and regulatory legibility. This architecture produced coherence, but it was not designed to make interoperable local energy communities emerge spontaneously.

This is not about assigning blame to any one actor. Municipalities, electricity syndicates, grid operators, and service providers do not, when taken in isolation, currently possess the conceptual and technical means to bring to scale what European texts have made possible. Each acts within its own perimeter, obligations, constraints, tools, and timelines. Yet a Citizen Energy Community is not merely an administrative perimeter, nor an extra contract added to the existing system. It is a form of organization that requires an explicit coordination layer.

Much of the current gap lies precisely there: between the physical electricity infrastructure and commercial or institutional services, a common standardization layer is missing. Without that layer, each local project tends to become an exception, a custom integration, or an ad hoc construction dependent on a specific operator, legal arrangement, or proprietary tool. In such a context, it becomes difficult to compare approaches, reproduce results, mutualize innovation, or guarantee interoperability.

The history of the Internet offers a structuring analogy here. The Internet did not emerge because a single actor owned all infrastructure, all uses, and all interfaces. It scaled because a clear separation took hold between physical layers, open protocols, and services. That separation enabled cooperation among heterogeneous actors without requiring institutional uniformity.

OpenCEC starts from that intuition. If Citizen Energy Communities are to become something more than a collection of local experiments that are hard to reproduce, they need an open protocol layer. That layer is not meant to replace the electricity grid, public actors, or service providers. It is meant to define common rules of cooperation among autonomous energy actors.

This document therefore rests on a double observation. On the one hand, Europe has created a political and legal possibility that remains under-instrumented. On the other hand, existing national structures, even when robust and legitimate, are not sufficient on their own to produce the expected interoperability. What is missing is not only goodwill or financing. What is missing is a common language, a common architecture, and common mechanisms.

OpenCEC 0.1 should be read as a first proposal for that architecture. It is neither a militant manifesto, nor a disguised commercial offer, nor an attempt at institutional capture. It is a specification project. Its ambition is both more modest and more demanding: to establish the principles, objects, invariants, and interfaces that will allow energy communities to cooperate in a transparent, verifiable, and evolutive way.

From this perspective, the core problem is not which actor “owns” the community, but how different actors can act together without depending on a technical or contractual black box. The fundamental question is not only economic. It is also epistemic, institutional, and democratic: how to make coordination rules legible, debatable, auditable, and shareable.

This foreword therefore provides the reading frame for the rest of the document. The specification that follows goes into the details of principles, algorithms, allocation mechanisms, pricing functions, technical protocols, and interoperability conditions. But before entering those details, it is useful to state clearly the historical problem OpenCEC seeks to address: the absence, in the field of energy communities, of an open layer comparable to what protocols represented for the Internet.

5. Abstract

OpenCEC 0.1 is a working specification for an open coordination layer dedicated to Citizen Energy Communities. Its goal is not to define a new category of electricity supplier, but to define a public protocol space in which volume allocation, fair price discovery, technical messaging, interoperability, and explicit service remuneration can be specified independently.

The central thesis of the document is that Citizen Energy Communities require the same conceptual separation that made the Internet scalable: infrastructure, protocols, and services should remain distinguishable. OpenCEC extends this analogy by adding an explicitly economic layer. OpenCEC is not merely an Internet of electricity flows; it is also a protocol layer for democratic price discovery.

Version `0.1` proposes:

- a separation between volume allocation and price discovery;
- the CLAIRE three-stage volume profile: self-consumption by legal entity, full mutualisation of residual production, then ordered priority-family water filling;
- a four-component pricing model based on volume, balance, network, and forecast;
- an MQTT-oriented protocol profile with transport independence as a design principle;
- an interoperability model for federation, roaming, and settlement across communities;
- a governance path inspired by public standards and RFC-like review processes;
- an initial compliance framework intended to support future tests and certification.

This version should be read as a substantive scientific draft: precise enough to be implemented, criticized, simulated, and improved, but still open enough to accept better algorithms, better transports, and better institutional arrangements in subsequent versions.

6. Introduction

6.1. Normative language

The key words `MUST`, `MUST NOT`, `SHOULD`, and `MAY` in this document are to be interpreted in the sense of RFC 2119.

- `MUST` indicates an absolute protocol requirement.
- `MUST NOT` indicates an absolute prohibition for compliance.
- `SHOULD` indicates a strong recommendation that may admit limited exceptions if explicitly justified.
- `MAY` indicates an optional behavior compatible with the protocol.

This document also distinguishes between four kinds of content:

- `normative requirements`, which define compliance;
- `examples`, which illustrate but do not bind;
- `reference implementations`, which demonstrate but do not define the protocol;
- `research hypotheses`, which motivate future work but are not themselves compliance criteria.

OpenCEC compliance is defined by protocol behavior, not by the use of a specific company, software stack, PMO, meter vendor, or hardware device.

European energy law has created room for Citizen Energy Communities, Renewable Energy Communities, and broader energy-sharing schemes. Yet the technical and economic tooling available to these communities remains fragmented. In practice, local projects are often assembled as special-purpose stacks that mix hardware integration, accounting conventions, software interfaces, and service remuneration without a stable public protocol layer.

OpenCEC starts from a simple diagnosis: a community that depends on a proprietary or opaque stack may exist as a project, but it cannot easily become a reproducible institution. What is missing is not only software. What is missing is a shared language for measurements, allocations, prices, rights, and auditable operations.

The Internet analogy is therefore more than rhetorical. Internet infrastructure is not reduced to one vertically integrated service provider. It separates physical transport, protocol layers, and end-user services. OpenCEC applies the same discipline to electricity communities:

- the electricity grid remains the physical infrastructure;
- OpenCEC defines a protocol layer for coordination and auditable exchange;
- multiple service providers may build software, hardware, maintenance, forecasting, or support services on top.

The important difference is that OpenCEC must also address economic coordination. A packet-switched network does not need to explain the fairness of a local energy allocation or the public logic of a dynamic community price. A Citizen Energy Community does. OpenCEC is not merely an Internet of electricity flows; it is also a protocol layer for democratic price discovery.

6.2. Internet analogy

Internet	**OpenCEC**
Physical cables	Electricity grid
IP	Energy identity and routing layer
TCP/UDP	Exchange protocols
DNS	Community discovery

HTTP	Service layer
Websites and apps	Energy services
RFC process	OpenCEC evolution process

Unlike the Internet, OpenCEC adds an explicit missing economic layer:

- distributed price discovery;
- value allocation;
- incentive mechanisms.

In that sense, OpenCEC can be understood as a first attempt at an `economic TCP/IP` for Citizen Energy Communities.

6.3. Layered architecture

OpenCEC is structured as a layered model:

- `Layer 0 - Physical electricity infrastructure`: grid, meters, production assets, storage assets.
- `Layer 1 - Measurement and identity`: PDLs, meter data, signatures, timestamps, actor identifiers.
- `Layer 2 - Allocation protocol`: rules determining who receives which energy volume.
- `Layer 3 - Economic protocol`: price discovery, fairness algorithms, settlement logic.
- `Layer 4 - Services`: applications, forecasting, optimization, maintenance, analytics, support.

6.3.1. Layer architecture diagram

Layer 4 Services, applications, forecasting, optimization, maintenance
Layer 3 Economic protocol: price discovery, settlement logic, fairness
Layer 2 Allocation protocol: volume distribution and community rules
Layer 1 Measurement and identity: meters, timestamps, actors, signatures
Layer 0 Physical electricity infrastructure: grid, assets, storage

Service providers `MUST` compete above the protocol. They `MUST NOT` own, redefine, or capture the protocol itself.

This document is intentionally scoped. It does not attempt to replace power-system regulation, physical network operation, taxation, or supplier obligations. It defines a coordination layer in which four questions can be answered in a transparent and interoperable way:

- who receives which energy volume;
- how a fair price is discovered;
- how messages and proofs are exchanged;
- which services remain billable, explicit, and replaceable.

The distinction between a CEC and a conventional electricity supplier is therefore decisive. A supplier primarily buys or procures electricity and resells it through commercial packaging. A CEC, in the OpenCEC sense, coordinates relations among autonomous actors: local production, consumption, flexibility, settlement, and governance. The purpose is not to hide margins inside a bundled tariff but to make the structure of value legible.

This distinction also explains why the price of electricity should not be represented as a single opaque number. OpenCEC insists on four constitutive dimensions of price:

- `volume`, because energy is a quantity exchanged;
- `balance`, because behavior may improve or degrade collective equilibrium;
- `network`, because electrical distance and infrastructure stress matter;
- `forecast`, because predictability and declared flexibility reduce uncertainty and cost.

OpenCEC 0.1 is written for researchers, regulators, municipalities, cooperatives, PMOs, and industrial implementers. Its aim is not to close debate but to move debate to a more rigorous level: definitions instead of slogans, explicit algorithms instead of discretionary arrangements, and protocol requirements instead of vendor-specific habits.

6.4. Basic notions

Basic notion: `ACI`

`ACI` refers here to `individual self-consumption`: the same actor produces electricity and consumes part of it directly, usually behind one meter or within one legal perimeter recognized as a single actor relation.

In practical terms, `ACI` is the simplest case. The economic and operational loop remains mostly internal to one producer-consumer identity, even if the public grid still matters for residual imports and exports.

Basic notion: `remote AC` or `deported ACI`

`Remote individual self-consumption` extends the same identity logic across several metering points or geographically separated assets belonging to the same actor. In French discussions this is often described as `ACI deporte` or multi-site self-consumption.

For OpenCEC, this case matters because it is the legal and operational bridge between single-site self-consumption and richer community coordination. It already requires explicit measurement, identity matching, and allocation rules across several points, even before one reaches a true community model.

Basic notion: `ACC`

`ACC` refers here to `collective self-consumption`, especially in the French sense: several participants share locally produced electricity through an explicit allocation key, a PMO, metering interfaces, and a recognized perimeter.

`ACC` is therefore not only a technical flow. It is an accounting, contractual, and governance arrangement. OpenCEC treats `ACC` as one important operational form of local energy sharing, but not as the whole concept of a `CEC`. A true `CEC` may include `ACC`, yet also extends to governance, investment, flexibility, interoperability, transparent pricing, and democratic control.

The distinctions above are important because the complexity does not grow only with distance or with the number of participants. It also grows with the need for explicit collective rules. `ACI` is mostly an internal optimization problem. `Remote AC` introduces multi-point identity and settlement. `ACC` introduces a collective coordination problem. `CEC` introduces a broader institutional and democratic architecture on top of that coordination problem.

6.5. Incidence on system and market functions

Citizen Energy Communities do not make system functions disappear. They reorganize how some of those functions are expressed, measured, valued, or delegated.

Balance responsibility and balancing perimeter

In liberalized electricity systems, energy injections and withdrawals are ultimately reconciled through a `balance responsible party` (`BRP`) or equivalent balancing perimeter. A `CEC` does not abolish that function.

What changes is that a well-structured `CEC` can improve the quality of the local residual profile presented to the upstream system. Better local matching, better forecast discipline, and explicit flexibility can reduce balancing costs, imbalance exposure, or forecasting error for the perimeter that ultimately carries balancing responsibility.

OpenCEC should therefore be read as complementary to `BRP` logic. It creates a transparent sub-layer of local coordination whose outputs can feed, rather than obscure, the wider balancing architecture.

Reserve, capacity, and demand response

`CECs` may also affect several neighboring functions:

- `reserve services`, when aggregated flexibility or storage can contribute to system support under the applicable market rules;
- `capacity mechanisms`, where local assets may contribute to adequacy if the legal framework recognizes them;
- `demand response` or `effacement`, where consumers or community assets deliberately reduce, shift, or shape load in response to price or dispatch signals;
- `congestion management`, where local coordination may reduce stress on a constrained distribution area.

OpenCEC does not replace these regulated functions. It makes their local technical and economic preconditions more explicit: who can modulate, under which signal, with which forecast commitment, with which measurement proof, and with which value-sharing rule.

The strategic consequence is important. A poorly designed community may merely hide complexity behind a local brand. A well-designed `CEC` can instead become a legible flexibility and forecasting layer that improves the relation between local actors, DSOs, aggregators, suppliers, and the balancing system.

For this reason, OpenCEC distinguishes sharply between:

- local coordination inside the community;
- explicit service interfaces toward balancing, reserve, capacity, or demand-response mechanisms;
- the regulatory responsibilities that remain outside the protocol itself.

The protocol should not pretend that a `CEC` becomes, by magic, a TSO, a DSO, a supplier, an aggregator, or a `BRP`. It should instead provide the shared objects through which a `CEC` can interact cleanly with those functions when national law allows it.

Open questions for later versions include deeper legal alignment with national implementations, stronger privacy profiles, and a larger library of benchmark algorithms. Those open questions do not prevent `0.1` from being used as a real working specification.

7. State of the Art of Energy Communities and Adjacent Models

OpenCEC does not emerge in an institutional vacuum. Many approaches already exist worldwide to organize local generation, flexibility, coordination, and distributed participation in electricity systems.

This chapter does not attempt a full literature review. Its purpose is to position OpenCEC relative to the main existing families of practice and design.

7.1. European Citizen Energy Communities

`Citizen Energy Communities` (`CECs`) are recognized in European electricity-market law as entities through which citizens, local authorities, and other eligible actors can organize participation in the energy system.

Objective:

- democratize energy participation;
- create local governance capacity;
- allow collective production, consumption, sharing, and services.

Strengths:

- strong legal legitimacy;
- explicit attention to participation and governance;
- broad potential scope beyond pure renewable production.

Limitations:

- uneven national implementation;
- weak technical standardization;
- high dependence on local project engineering and bespoke integrations.

Relationship with OpenCEC:

OpenCEC does not compete with the CEC concept. It seeks to provide the missing coordination layer that makes CECs interoperable, auditable, and reproducible across implementations.

7.2. Renewable Energy Communities

`Renewable Energy Communities` (`RECs`) are anchored more directly in renewable-energy law and often emphasize collective renewable generation and sharing.

Objective:

- accelerate renewable deployment;
- enable collective self-consumption and local renewable projects;
- widen access to renewable ownership.

Strengths:

- strong policy alignment with decarbonization;
- visible fit with photovoltaic, wind, and local generation projects;
- public legitimacy in the transition discourse.

Limitations:

- focus can remain generation-centric;
- governance and interoperability are often under-specified;
- economic coordination may remain opaque or platform-dependent.

Relationship with OpenCEC:

OpenCEC is compatible with REC logic but goes further by standardizing allocation, price discovery, messaging, and service separation.

7.3. Local Energy Markets

Local energy markets attempt to organize energy exchange, price signals, or flexibility transactions inside a neighborhood, feeder area, building cluster, or local system.

Objective:

- improve local matching of supply and demand;
- reveal local scarcity or abundance;
- coordinate flexibility near physical constraints.

Strengths:

- explicit treatment of local value;
- useful for congestion, flexibility, and distributed assets;
- often close to economic optimization questions.

Limitations:

- can become highly platform-centric;
- may over-financialize local coordination;
- frequently rely on proprietary rules and limited public auditability.

Relationship with OpenCEC:

OpenCEC shares the interest in local value discovery, but insists that the coordination rules themselves should become a public protocol rather than a proprietary market engine.

7.4. Peer-to-peer energy trading

Peer-to-peer (`P2P`) energy trading frames electricity coordination as exchange between peers rather than centralized supply.

Objective:

- allow direct exchange relationships;
- increase user autonomy;
- personalize energy transactions.

Strengths:

- strong intuitive appeal;
- visible challenge to supplier-centric models;
- useful experimentation ground for decentralized coordination.

Limitations:

- risks bilateral opacity or favoritism;
- may privilege trading rhetoric over community governance;
- can drift toward digital marketplace logic without deeper protocol discipline.

Relationship with OpenCEC:

OpenCEC keeps the decentralized ambition but replaces pure peer-trading imagery with a stronger emphasis on public rules, fairness, auditability, and collective intelligibility.

7.5. Virtual Power Plants

`Virtual Power Plants` (`VPPs`) aggregate distributed assets to act in a coordinated manner toward system operators or markets.

Objective:

- aggregate flexibility and distributed production;
- participate in balancing, reserve, or wholesale services;
- optimize portfolios of distributed assets.

Strengths:

- operational relevance for power systems;
- strong interface with existing market structures;
- proven value for aggregation and dispatch coordination.

Limitations:

- governance often remains top-down;
- end participants may see only partial transparency;
- optimization can primarily serve the aggregator rather than the community.

Relationship with OpenCEC:

OpenCEC does not reject aggregation. It asks that the community-side coordination logic remain visible and governable before aggregation toward larger markets occurs.

7.6. Demand response

Demand response coordinates load reduction, shifting, or modulation in response to grid or market conditions.

Objective:

- reduce peaks;
- improve system balance;
- mobilize flexible demand.

Strengths:

- high practical relevance;
- clear system benefits;
- compatible with many device categories.

Limitations:

- often utility-centric or aggregator-centric;
- signals may remain opaque to end users;
- does not by itself define a democratic community architecture.

Relationship with OpenCEC:

Demand response becomes one useful function inside OpenCEC, not the whole organizing principle.

7.7. Microgrids

Microgrids coordinate local production, loads, and sometimes storage within a bounded electrical system that may operate grid-connected or islanded.

Objective:

- local resilience;
- operational autonomy;
- local balancing and continuity.

Strengths:

- strong physical-system coherence;
- useful for resilience and islanding;
- close fit with control engineering.

Limitations:

- not all CECs are microgrids;
- governance and economic transparency may remain secondary;
- technical control can dominate over democratic design.

Relationship with OpenCEC:

OpenCEC can coexist with microgrids, but it is not limited to microgrid architecture. It addresses wider coordination, settlement, governance, and interoperability questions.

7.8. Comparative conclusion

The common pattern is instructive.

Most existing approaches optimize one of the following:

- a platform;
- an aggregator;
- a market opportunity;
- a local engineering project;
- a grid-service function;
- a renewable deployment objective.

OpenCEC addresses a different missing layer: the public standardization of coordination itself.

The historical analogy with the pre-Internet period is useful. Before `TCP/IP`, many networks already existed. The missing element was not another network. It was interoperability, public semantics, and a shared protocol discipline across heterogeneous systems.

OpenCEC aims to play an analogous role for energy communities: not replacing every local approach, but making them legible, interoperable, and less dependent on bespoke platform capture.

7.9. Comparative synthesis table

Model	Primary objective	Main strength	Main limitation vs OpenCEC
`CEC`	Citizen participation and community governance in the electricity system	Strong democratic and legal legitimacy	Often lacks a portable technical and economic coordination layer
`REC`	Collective renewable generation and sharing	Clear fit with renewable deployment	Can remain generation-centric and weakly standardized
`Local energy market`	Reveal local value and coordinate local exchange	Strong focus on local optimization	Can become proprietary or over-financialized

`P2P energy trading`	Direct exchange between peers	Strong autonomy narrative	May privilege trading rhetoric over public community rules
`VPP`	Aggregate distributed assets for system or market participation	Operational relevance and market interface	Often aggregator-centric rather than community-centric
`Demand response`	Shift or reduce load under signals	High practical value for flexibility	Too narrow to define a full CEC architecture
`Microgrid`	Local operational autonomy and resilience	Strong physical coherence	Does not by itself solve governance and economic transparency
`OpenCEC`	Standardize the coordination layer itself	Interoperability, auditability, and public economic semantics	Requires progressive adoption and multi-actor standardization effort

8. Energy Time and Energy Space

One of the easiest mistakes in electricity thinking is to treat every `kWh` as if it were interchangeable with every other `kWh`.

This simplification is acceptable for some accounting purposes, but it is not sufficient for community coordination. In OpenCEC, a `kWh` is not only a quantity. It is a situated event.

8.1. Why electricity is not like Internet data

The Internet analogy is useful, but it has strict limits.

Internet packets:

- can often tolerate delay;
- can be duplicated without changing physical reality;
- can be stored easily at low marginal cost;
- are not governed by Kirchhoff-like physical constraints in the same direct sense as electricity flows.

Electricity differs on every decisive point:

- supply and demand must remain balanced at every moment;
- physical location matters because networks are constrained;
- one cannot simply duplicate useful electrical availability at zero cost;
- storage exists, but it is costly, lossy, and capacity-constrained;
- forecast quality has direct operational and economic consequences.

This is why OpenCEC needs more than a messaging layer. It needs protocol objects that explicitly represent:

- time;
- location;
- predictability;
- flexibility;
- local network relevance;
- economic value.

This also justifies the long-term interest in a more native protocol such as `Alpha`.

8.2. A multidimensional kWh

For OpenCEC, the relevant value of a `kWh` is shaped by at least six dimensions:

- `timestamp`;
- `location`;
- `availability`;
- `predictability`;
- `flexibility value`;
- `grid impact`.

The same energy quantity can therefore have very different meaning in practice.

Example:

- `1 kWh` of local solar surplus at noon on a low-congestion day;
- `1 kWh` available during a winter evening peak;
- `1 kWh` delivered from a predictable battery response;
- `1 kWh` associated with uncertain forecast error.

These are not equivalent objects from the viewpoint of a real CEC.

8.3. Energy time

Electricity has a temporal structure that is not optional.

An energy community must reason about:

- instant state;
- short settlement periods;
- forecast horizons;
- activation deadlines;
- persistence of flexibility;
- historical replay.

This means that protocol objects should never be thought of as timeless records. They are time-bounded propositions about a dynamic system.

For example, a flexibility offer without deadline, validity window, or confidence is not a serious operational object.

8.4. Energy space

Electricity also has a spatial structure.

Even when a legal framework uses simplified perimeters, the underlying system still contains:

- feeders;
- transformers;
- voltage levels;
- line constraints;
- local congestion zones;
- varying electrical distance between actors.

OpenCEC does not need to expose the full complexity of power-flow engineering in every message. But it should remain aware that “local” is never a purely rhetorical word. It has operational consequences.

This is why the network dimension of price and allocation cannot be reduced to branding language such as `local green energy`. Locality must correspond to a measurable relation with the network.

8.5. Addressing energy value

The protocol consequence is important. OpenCEC can be understood as an addressing system for multidimensional energy value.

It helps answer not only:

- who produced;
- who consumed;
- how much was exchanged;

but also:

- when it mattered;
- where it mattered;
- under which predictability conditions;
- with which flexibility contribution;
- with which effect on the local grid.

In this sense, OpenCEC extends the Internet analogy. The Internet needed addressing for communication objects. Energy communities need addressing for economically and physically situated electrical objects.

9. Foundational Principles

The principles in this chapter are normative. They are not decorative values and they are not optional aspirations. They define the minimum architecture that distinguishes OpenCEC from a supplier-centric, opaque, or purely rhetorical community-energy stack.

9.0.1. Axiom 1: Transparency

All algorithms that materially affect allocation, price discovery, flexibility valuation, or settlement should be public and inspectable. Inputs, parameters, and outputs should be auditable. A participant does not need to understand every mathematical detail, but no participant should be forced to trust an unverifiable black box.

9.0.2. Axiom 2: Non-discrimination

Equivalent consumers in the same energy context should pay the same protocol-level price, and equivalent producers in the same context should receive the same protocol-level price. OpenCEC does not prohibit all bilateral contracts in the wider legal world, but it rejects opaque bilateral favoritism inside the protocol layer itself.

9.0.3. Axiom 3: Separation of energy and service

A PMO is not an energy supplier by default. Service fees should be explicit and externalized from the kWh. At the protocol level, the producer-side and consumer-side energy price should not be separated by an invisible intermediary margin.

9.0.4. Clarifying contrast with supplier logic

This axiom is the clearest boundary between OpenCEC and a conventional supplier model.

In a supplier logic:

- electricity is a commercial product sold by an intermediary;
- the customer generally faces an offer whose internal construction is only partially visible;
- margins, hedging, packaging, and commercial positioning are concentrated in the supplier layer.

In an OpenCEC logic:

- the protocol does not justify an intermediary energy margin between community producer and community consumer;
- the relevant service providers remain identifiable and are paid explicitly for software, hardware, maintenance, operations, or support;
- the community layer exists to coordinate, not to disguise resale.

This difference also appears in price intelligibility. A supplier can publish a tariff without exposing the physical and cooperative structure behind it. OpenCEC should do the opposite and make explicit the four dimensions that shape electricity value: `volume`, `balance`, `network`, and `forecast`.

An implementation that reproduces supplier economics while merely changing the vocabulary should not be considered faithful to the OpenCEC model.

9.0.5. Axiom 4: Real citizen investment

Citizen investment should correspond to a physical asset or to an equally explicit operational right. Assets should have measurable production or flexibility contribution. Their expected lifetime, maintenance responsibilities, and accountability chain should be documented.

9.0.6. Axiom 5: Algorithmic auditability

An implementation should make it possible to replay, inspect, and test the main allocation and pricing outputs from retained inputs and versioned logic. If a result cannot be audited, it should not count as protocol-grade.

9.0.7. Axiom 6: Replaceability of implementations

Implementations may vary, but no implementation should own the protocol. Data export, migration, and reproducible interfaces are therefore part of the normative architecture.

9.0.8. Derived properties

Taken together, the axioms above imply auditability, interoperability, resistance to hidden margins, and compatibility with plural implementation ecosystems.

9.1. Compliance requirement

Any actor claiming conformity with the present specification should comply with all normative principles of OpenCEC without derogation.

Conformity should not be claimed on a selective basis, by retaining only the technically convenient parts while bypassing the economic, democratic, or transparency constraints that give the specification its meaning. An implementation that violates one of the core principles may be technically inspired by OpenCEC, but should not present itself as OpenCEC-compliant.

For operational clarity, the full set of principles should later be summarized in a dedicated compliance table. That summary is introduced in Annex E and is intended to support future audit, labeling, and public communication processes.

9.2. Meta-principles

Beyond the detailed axioms, two meta-principles define the institutional DNA of OpenCEC and orient it toward an economic, ecological, and democratic optimum.

9.2.1. Meta-principle 1: no intermediary margin inside the energy exchange

There should be no intermediary capturing a hidden margin between producer and consumer inside the energy community. Consequently, at the protocol level, the sale price should equal the purchase price, and value creation should be made visible outside the kWh itself, in explicitly billed services.

This also implies a strong vigilance against supra-local fiscal or parafiscal layers that would reintroduce opaque extraction mechanisms disconnected from the actual local energy cooperation.

9.2.2. Meta-principle 2: dynamic price determined by the network itself

The price should be dynamic, determined at every moment and in every place by the state of the network and by the public rules of the protocol, not by a financial exchange, not by discretionary human arbitration, and not by opportunistic political decision.

This does not mean the absence of governance. It means that governance should define public rules and parameters, while the actual price formation emerges continuously from the network situation, measurable constraints, and protocol-defined signals.

Operationally, this dynamic price should remain interpretable through four constitutive dimensions: `volume`, `balance`, `network`, and `forecast`.

10. Volume Allocation

Volume allocation answers a question that must remain independent from price discovery: for each settlement interval, which delivery point receives which part of the measured community production. It is a physical-accounting attribution of energy volume. It is neither a retail sale, a price, nor a transfer of title to an electron.

OpenCEC separates this operation from valuation because an allocation rule can be fair, reproducible, and lawful only when it can be replayed from its metering and perimeter inputs. A price model may subsequently value the allocated volumes, but it must not alter them retroactively or conceal a volume-allocation choice in a bill.

10.1. Normative language and scope

The words `MUST`, `MUST NOT`, `SHOULD`, and `MAY` in this chapter are normative. The requirements apply independently to every settlement interval. The reference field profile uses intervals of `15 minutes`; another interval duration is permitted only when declared in the allocation version and supported by the applicable settlement operator.

The algorithm takes place after measurement and before price discovery. It produces a vector of attributed energy volumes in Wh, together with the evidence needed to reproduce the vector.

10.2. Definitions and notation

For a settlement interval t:

- D_t is the set of active consumer delivery points;
- G_t is the set of active production delivery points;
- $d_{i(t)} \geq 0$ is measured consumption in Wh at consumer delivery point i;
- $q_{g(t)} \geq 0$ is measured production in Wh at production delivery point g;
- $Q(t) = \sum_{g \in G_t} q_{g(t)}$ is total measured community production;
- $C(t) = \sum_{i \in D_t} d_{i(t)}$ is total measured active demand;
- $E(t) = \min(Q(t), C(t))$ is the maximum collectivisable energy volume;
- $a_{i(t)}$ is the allocated community volume at delivery point i;
- $u_{i(t)} = d_{i(t)} - a_{i(t)}$ is the uncovered demand.

`Active` is a property of the dated perimeter, not merely of the existence of a meter file. A delivery point is active at t only when its declared participation interval contains t. A delivery point that begins or ends participation during a month must therefore enter or leave the calculation on its effective date.

10.3. Non-negotiable invariants

Every valid allocation vector must satisfy:

$0 \leq a_{i(t)} \leq d_{i(t)}$ for every $i \in D_t$;

$a_{i(t)} = 0$ for every inactive delivery point;

$\sum_{i \in D_t} a_{i(t)} \leq E(t)$;

$\sum_{i \in D_t} a_{i(t)} = 0$ when $Q(t) = 0$ or $C(t) = 0$.

The final surplus is $Q(t) - \sum_{i \in D_t} a_{i(t)}$. Consequently, production is never allocated beyond contemporaneous active demand and an allocation is never negative. The equality $\sum_i a_{i(t)} = E(t)$ holds when the CLAIRE stages expose sufficient eligible residual capacity; otherwise the unapplied part of $E(t)$ remains surplus because no lower-level or unconfigured beneficiary may receive it.

10.4. Perimeter and input evidence

Before any computation, an implementation `MUST` construct a versioned perimeter register. For each delivery point it must retain:

- a stable delivery-point identifier;
- its role or roles: consumer, producer, storage, or another declared role;
- start and end of participation;
- the legal or natural-person group, where the selected allocation profile needs it;
- the source and version of the perimeter record.

The calculation input for interval t must also retain the measured consumption and production values, their source, measurement status, time zone, interval duration, and any correction version. Missing measurement data must not silently be replaced with an ordinary measured zero. The interval must be rejected and settled only after a versioned correction process. The rejection and later correction must remain visible in the allocation evidence.

The reference ACC workflow demonstrates why this is necessary: the perimeter can change in the middle of a settlement month. A newly attached consumer must receive no allocation before its activation date; an expired delivery point must no longer appear as active after its end date.

10.5. Edge-condition boundary

The following conditions must be resolved in the dated configuration or rejected before a CLAIRE calculation. A calculation must not invent a legal-entity relationship, energy origin, or measurement value to obtain a result.

- A jointly owned asset, a delivery point with several holders, or a legal entity under succession, insolvency, merger, or split must identify the legal entity that holds the allocation right for the effective interval.
- A storage asset must declare whether its measured export is eligible production, the applicable loss model, and the rule preventing the same source volume from being attributed twice. Storage state is not a substitute for interval production evidence.
- A production volume subject to a binding prior allocation, export commitment, curtailment order, or national eligibility restriction must be excluded or constrained by a declared applicable profile before CLAIRE begins.
- A missing, estimated, negative, duplicate, or mutually inconsistent measurement must be represented by its quality status. It must be rejected, corrected, or processed only under a published estimation rule. It must never be silently converted to ordinary zero.
- A change of occupant, account holder, or representation must not retrospectively modify an allocation unless the applicable legal and settlement rules require a versioned correction.

These rules do not resolve national property or settlement law. They make the dependency visible and prevent an implementation from silently converting an unresolved legal fact into an algorithmic preference.

10.6. CLAIRE-1.0: normative OpenCEC volume profile

OpenCEC 0.1 adopts `CLAIRE-1.0 (Collective Local Allocation by Impartial Resource Equalization)` as its normative volume-allocation profile. CLAIRE has three compulsory stages, executed independently in every settlement interval:

1. `level 0`: each legal entity first receives its own production across its own consumer delivery points;
2. `mutualisation`: every legal entity's residual production enters one collective reservoir;

3. `priority families`: the collective reservoir is allocated by water filling to configured consumer families, in strict priority order.

An allocation run claiming OpenCEC conformance must identify `CLAIRE-1.0`, the dated legal-entity register, and the dated priority-family configuration. A delivery-point-only water-filling implementation may be used as a national-adapter compatibility mechanism, but it must not claim conformance with this core profile unless it implements all three stages.

10.6.1. Level 0: remote individual self-consumption by legal entity

Let P_e be the total production of legal entity e, and I_e the set of its active consumer delivery points. CLAIRE initializes every assigned volume at zero and applies water filling independently to each I_e with available energy P_e. Therefore the level-0 volume A_i^0 for delivery point i is limited by its measured consumption and the total production of its own entity.

The residual production of entity e is:

$$P_e^{R(t)} = P_{e(t)} - \sum_{i \in I_e} A_i^0(t).$$

No production of entity e may satisfy consumption of another entity before the level-0 calculation has completed for every entity. An entity without consumer delivery points contributes all its production to its residual production; an entity without production receives no level-0 volume.

The legal-entity mapping must be explicit and versioned. It must not be inferred from a display name, billing address, platform account, or similarity of identifiers.

10.6.2. Mutualisation and producer neutrality

After level 0, the collective reservoir is:

$$E_{\text{collective}(t)} = \sum_e P_e^{R(t)}.$$

The original producer identity must no longer influence the allocation of this reservoir. After mutualisation, splitting one producer's measured production into several production delivery points, or merging production delivery points, must not change the collective result when total production and every other input remain unchanged.

10.6.3. Priority families

A priority family is an ordered, versioned set of consumer delivery points eligible to receive collective residual production. The governance configuration must publish:

- the family identifier;
- its priority level, with lower number processed first;
- its effective period;
- its admissible consumer delivery points;
- the rule for a delivery point that is listed in more than one family.

By default, a delivery point is eligible only in the highest-priority active family in which it appears. Any other overlap rule is non-conformant unless it is standardized in a later OpenCEC version. Families are a governance input decided before execution; the PMO or any operator must not alter family membership or choose volumes after seeing the interval measurements.

For each family F_k in increasing priority order, let $R_{i(t)} = \max\left(0, d_{i(t)} - A_{i(t)}\right)$ be each member's residual capacity. CLAIRE applies water filling to the members of F_k whose residual capacity is positive, using the remaining collective reservoir. The resulting incremental volume is added to $A_{i(t)}$ before the next family is considered. A lower-priority family receives nothing while an earlier family has positive residual capacity and collective energy remains.

Priority families are a constitutional rule, not an operator discretion. Their creating decision must state the public-interest purpose, eligibility condition, affected delivery points, effective date, review date, and contestation route. A family must not be used to encode a hidden individual coefficient, an undisclosed capital preference, or a post-measurement favour. Its membership and priority must be frozen for each interval before the relevant measurements become available. The dated configuration must retain the approving governance decision.

The calculation ends when the reservoir is empty, every active family has been processed, or no eligible residual capacity remains. Any remaining reservoir is surplus production.

10.6.4. Compatibility boundary: DP-WF-0.1

The previously described `DP-WF-0.1` procedure distributes available production directly among active consumer delivery points. It is useful as a documented field baseline and for testing a national key-submission adapter. It omits CLAIRE level 0 and priority families. It is therefore an `OpenCEC experimental transport profile`, not a CLAIRE-1.0 or full OpenCEC 0.1 volume-allocation implementation.

10.7. Water-filling algorithm

For every CLAIRE level, initialise the incremental volume to zero for the admissible active consumer delivery points. Let R be the energy available to that level and let $A = \{i \in I \mid R_i > 0\}$, where I is the level's beneficiary set and R_i its residual capacity.

```
while R > 0 and A is not empty:
    h = min(R / |A|, min(i in A, d_i - a_i))
    for each i in A:
        a_i = a_i + h
    R = R - h * |A|
    A = {i in A | a_i < d_i}
```

At each iteration, every still-unsatisfied beneficiary receives the same layer of energy. A small demand reaches its cap first, then exits the active set. The remaining energy is shared equally between the remaining unsatisfied beneficiaries. The algorithm ends because each iteration either exhausts residual energy or saturates at least one delivery point.

This algorithm is equivalent to the unique filling level $\lambda \geq 0$ satisfying $\sum_{i \in I} \min(R_i, \lambda) = \min\left(R, \sum_{i \in I} R_i\right)$. The incremental allocation is $X_i = \min(R_i, \lambda)$. These equations prevail over pseudo-code in case of any ambiguity.

10.8. Integer Wh allocation and deterministic rounding

Measurements and settlement exports are commonly expressed in integer Wh. Water filling may yield fractional Wh. An implementation that exports integer Wh must perform a conservation-preserving integerization:

1. compute the real-valued allocation a_i;
2. allocate $\lfloor a_i \rfloor$ Wh to each beneficiary, never above d_i;
3. distribute the remaining whole Wh one at a time to eligible beneficiaries in decreasing order of fractional remainder;
4. when fractional remainders are equal, apply the declared deterministic tie-breaker;
5. stop only when the integer allocation totals exactly $E(t)$.

The tie-breaker must be published in the algorithm version. It is a representation rule, not a hidden priority rule. Strict anonymity holds for the continuous water-filling allocation; at an indivisible 1-Wh boundary, a deterministic tie-breaker is required for replayability and must be disclosed.

10.9. Allocation keys as a transport representation

Some settlement interfaces request percentage keys rather than Wh volumes. A key is a representation of the already computed allocation; it is not the allocation algorithm itself.

For an interval where the final total assigned volume is positive, the key for active consumer delivery point i is:

$k_{i(t)} = 100 * \frac{A_{i(t)}}{\sum_j} A_{j(t)}.$

For an interval where the final total assigned volume is zero, every active consumer delivery point receives key 0.0. Keys may be rounded for transport, but their rounded values must sum to exactly `100.00` whenever the final total assigned volume is positive. The remaining hundredth of a percent must be assigned by the declared deterministic correction rule. The reference profile corrects the last non-zero beneficiary in a documented stable ordering.

An ENEDIS-compatible field adapter must emit a key for every active consumer PRM in every interval, including a `0.0` key. It must omit delivery points that are not active in that interval. This distinction is material: omitting an active zero-key PRM makes the external submission invalid, while including an inactive PRM misrepresents the dated perimeter.

10.10. Time, calendar, and transport requirements

Every allocation record must carry:

- `allocation_version` and selected profile;
- agreement or CEC identifier;
- interval start and end in UTC, plus the source local time zone;
- interval duration;
- perimeter version and active delivery-point set;
- source measurement identifiers and correction status;
- production `Q(t)`, demand `C(t)`, collectivisable volume `E(t)`, surplus, and allocation vector;
- integerization and key-rounding rule identifiers;
- content hash or integrity proof of the input and output set.

Local timestamps must be converted with an explicit IANA time-zone rule, including daylight-saving transitions. A fixed `UTC+2` conversion may be valid for an interval known to be wholly in CEST, but it is not a general OpenCEC conversion rule and must not be used without that proof.

10.11. Worked delivery-point example

Let three active delivery points have demands `(8, 4, 2)` kWh and let the collectivisable energy be `9` kWh. The first layer allocates `(2, 2, 2)` kWh. The third delivery point is saturated. The remaining `3` kWh are shared between the first two points, giving final allocations `(3.5, 3.5, 2)` kWh.

A proportional rule would yield approximately `(5.14, 2.57, 1.29)`; a priority queue with the order `A, B, C` would yield `(8, 1, 0)`. Water filling instead progressively equalizes uncovered demand: `(4.5, 0.5, 0)` kWh remain uncovered.

10.12. Audit, correction, and reproducibility

An allocation record is auditable only if a third party can replay it. The minimum replay package contains the dated perimeter, raw or corrected interval measurements, selected profile, identity-group register when relevant, source code or executable algorithm identifier, rounding rule, resulting Wh allocation, and resulting transport keys.

If a meter correction or a perimeter correction changes a past input, the implementation must create a new allocation version. It must preserve the previous allocation, identify the superseded intervals, explain the correction reason, and prevent two versions from being silently used in the same settlement calculation.

10.13. Formal properties and limits

CLAIRE-1.0 has the following properties:

- feasibility and conservation;
- full use of energy available to each level when eligible residual capacity exists;
- symmetry for beneficiaries with equal demand;
- monotonicity with respect to available production;
- no queue-order advantage;
- no bilateral producer-consumer favoritism after level 0;
- progressive equalization of uncovered demand.

It does not establish every possible fairness objective. Priority families are the only individual differentiation mechanism in CLAIRE-1.0, and they operate on a public predeclared group basis, never as a per-person coefficient. The profile does not reward capital contribution, prior investment, geographical priority, or consumption reduction except where these are expressed through a published family configuration. Any later profile that adds another factor must state which property it relaxes and must not conceal it in the implementation.

10.14. Mandatory conformance cases

The following unrounded cases are mandatory for a CLAIRE-1.0 conformance suite.

Test	Input	Expected result	Property
`C1`	demands `(2, 6)`; energy `4`	assigned `(2, 2)`	equal incremental volume
`C2`	demands `(2, 5, 10)`; energy `9`	assigned `(2, 3.5, 3.5)`	successive saturation
`C3`	demands `(4, 4, 4)`; energy `6`	assigned `(2, 2, 2)`	symmetry
`C4`	demands `(1, 3, 8)`; energy `20`	assigned `(1, 3, 8)`; surplus `8`	bounds and surplus
`C5`	family 1 demands `(2, 3)`; family 2 demand `10`; collective energy `7`	family 1 `(2, 3)`; family 2 2	strict family priority
`C6`	entity 1 produces `6`, demands `(2, 3)`; another entity demand `10`	level `0` `(2, 3)`; collective reservoir `1`	level 0 before mutualisation
`C7`	any identifier permutation of `C2`	same identifier-to-volume association	order invariance
`C8`	collective production `10`, then fragments `3 + 7`	same collective result	producer neutrality

A conformance suite must additionally generate randomized cases and verify conservation, non-negativity, individual bounds, permutation invariance, absence of double assignment, and equality with a reference implementation.

11. Fair Price Discovery

11.1. Central thesis

In OpenCEC, the price of electricity should not be treated as a flat commercial tariff. It should be understood as the synthetic expression of four distinct dimensions that together describe the real economic and physical situation of electricity exchange.

These four dimensions are:

- volume;
- balance;
- network;
- forecast.

Insisting on these four dimensions is essential because they are precisely what distinguishes an electricity protocol from a conventional supply offer. A conventional supplier can hide complexity behind a bundled tariff. A CEC should instead make the structure of value legible.

11.2. Core model

$P = P_V + P_E + P_R + P_F$

Where:

- P_V is the volume component.
- P_E is the balance component.
- P_R is the network component.
- P_F is the forecast component.

Inputs:

- allocated energy volumes;
- balance indicators;
- network-related indicators or locality metrics;
- forecast and flexibility quality indicators;
- a public parameter set.

Outputs:

- a total price;
- a visible decomposition into the four components;
- settlement elements usable for participant-level or period-level accounting.

Invariants:

- transparency;
- reproducibility;
- visible component decomposition;
- absence of hidden intermediary margin at protocol level.

Constraints:

- the same inputs under the same public parameter set `MUST` produce the same result;
- the algorithm `MUST` be replayable from archived inputs;
- the algorithm `MUST NOT` hide value transfer inside undocumented spreads.

This formulation should be read as more than a mathematical shorthand. It expresses that the price of electricity always has at least four interpretable dimensions:

- a `volume` dimension, because energy is first a quantity exchanged;
- a `balance` dimension, because not all kWh have the same effect on local and system equilibrium;
- a `network` dimension, because electrical distance and infrastructure stress matter;
- a `forecast` dimension, because predictable behavior reduces collective cost and uncertainty.

OpenCEC does not fix a single price schedule for all communities. It fixes a public structure for price discovery. The community should therefore be able to explain not only the total price, but the contribution of each component.

A price-discovery algorithm `MUST` satisfy at least:

- an explicit accounting boundary before it claims conservation of exchanged value;
- transparency;
- reproducibility;
- no hidden margin.

11.3. Component interpretation

11.3.1. Volume component

P_V represents the base energy value of exchanged kWh. It may depend on time granularity, local policy, or a reference tariff, but its role should remain intelligible: it is the part of price linked to quantity itself.

11.3.2. Balance component

P_E rewards or penalizes the contribution of a behavior to local or system balance. A participant who improves coincidence between available production and demand, or who delivers declared flexibility at useful moments, should tend to reduce collective balancing costs.

11.3.3. Network component

P_R reflects network usage. It is the place where electrical distance, congestion sensitivity, and a LAN/WAN-like view of locality can be expressed. Two kWh are not economically identical if one creates far more infrastructural stress or requires longer effective routing.

11.3.4. Forecast component

P_F reflects predictability. Accurate forecasts, declared flexibility windows, and operational discipline reduce uncertainty and therefore reduce community cost. Conversely, persistent absence of forecast or systematically poor declarations may justify a penalty.

11.4. Shape of pricing functions

Each component may use a linear or convex form.

Linear forms are easier to explain and test. Convex forms may be justified where the protocol aims to:

- discourage peaks or extreme imbalances;
- encourage sobriety near stressed states;
- avoid subsidizing behavior that imposes disproportionate cost on others.

Convexity is therefore not a mathematical ornament. It is a governance choice about how severely the protocol reacts to collective stress.

11.5. Algorithmic democracy

Some parameters of the price model are tunable and therefore political in a legitimate sense. OpenCEC should not hide that fact. Instead, it should expose the parameters and allow public choice mechanisms.

When a scalar parameter must be selected collectively, the median vote is a strong default candidate. If each participant proposes a preferred value x_i, then the median of the proposed values minimizes the sum of absolute deviations $\sum_i |x - x_i|$.

The median therefore minimizes aggregate absolute dissatisfaction. This gives a short and robust mathematical justification for using median choice in protocol governance where one-dimensional parameter selection is needed.

11.6. Interpretive summary

An OpenCEC-compliant pricing approach should therefore always be explainable through these four lenses: `volume`, `balance`, `network`, and `forecast`.

If one of these dimensions is absent, hidden, or absorbed into an opaque commercial spread, the system risks falling back toward supplier logic rather than community logic.

Open question: later versions should specify benchmark formulas and publish comparative simulations so that communities can compare several admissible pricing functions without losing interoperability.

11.7. Comparison with financial electricity markets

OpenCEC price discovery should not be confused with the logic of wholesale or financial electricity markets.

Wholesale markets primarily answer a globalized commodity question:

- what is electricity worth in a broader market under large-scale supply-demand conditions.

OpenCEC answers a situated community question:

- what is this `kWh` worth here and now, given local availability, local balance, local network conditions, and local forecast quality.

This difference is not cosmetic.

Wholesale market logic is optimized for:

- large-scale procurement;
- portfolio hedging;
- commodity exchange;
- system-wide balancing frameworks.

OpenCEC is optimized for:

- local physical usefulness;
- community fairness;
- transparent coordination;
- explicit value-sharing under local constraints.

The objective is therefore not to deny the existence of larger markets, but to avoid collapsing all local energy value into a single abstract commodity price detached from place, time, and community usefulness.

12. Price-Discovery Boundary and Future Settlement Profile

This chapter is **NORMATIVE** only for the transparency boundary below. It deliberately does not turn the four-component price architecture into a universal tariff. A community must not claim that a pricing function is OpenCEC-certified merely because it labels four numbers P_V, P_E, P_R, and P_F.

12.1. Core transparency boundary

An `OpenCEC-Core-0.1` implementation that produces a participant-facing energy price must publish a price statement for each settlement period. The statement must identify the applicable currency, period, allocated Wh, public parameter-set identifier, and each component used. It must separately show regulated charges, taxes, supplier charges, explicit service fees, credits, corrections, and amounts that are outside the OpenCEC calculation.

The statement must specify the unit, sign convention, payer, recipient, and legal or contractual basis of every monetary component. A negative component is a credit; it must not be displayed as a hidden reduction of another component. The implementation must preserve a replay package sufficient to reproduce the displayed statement from versioned inputs. `P = P_V + P_E + P_R + P_F` is a decomposition of a community calculation; it does not override regulated network tariffs, tax rules, supplier invoices, balancing obligations, or consumer-protection law.

12.2. No false conservation claim

The phrase `conservation of exchanged value` is valid only when the accounting boundary is declared. A settlement profile must state whether its ledger includes community credits, participant debits, taxes, regulated charges, service fees, losses, bad debt, external-market settlement, and rounding residuals. It must identify the account receiving any non-zero residual. Until then, a pricing design may claim transparency and replayability, but not monetary conservation.

12.3. Future settlement profile requirements

A future normative price-and-settlement profile must define, at minimum:

- the interval and billing-period boundaries, time zone, currency, decimal precision, and rounding order;
- each input, unit, sign convention, permitted parameter range, and formula;
- the allocation of each debit and credit to an identified account;
- caps, floors, consumer-protection constraints, correction and dispute procedures;
- treatment of tax, network charges, supplier obligations, BRP obligations, and explicit service remuneration;
- the relationship between a forecast incentive and the evidence available to contest it;
- test vectors covering zero volume, negative credits, correction, missing data, and a full balanced ledger.

Until such a profile is adopted, the four-component model is an **INFORMATIVE architecture** and a mandatory transparency vocabulary, not a mandatory universal pricing formula.

13. Protocol Layer

OpenCEC requires an event-oriented communication layer because measurements, forecasts, allocations, flexibility announcements, and price vectors are inherently time-dependent and multiparty. A pure request/response abstraction is too narrow as a primary mental model. Communities need asynchronous publication, replay tolerance, and near-real-time dissemination of protocol objects.

MQTT is retained in `0.1` as the main candidate transport profile because it is lightweight, widely implemented, and suitable for many distributed energy-device environments. This choice does not eliminate transport independence as a long-term design principle. What matters is the protocol semantics: topics, payloads, signatures, timing semantics, and capability discovery.

MQTT remains useful because it is:

- widely deployed;
- robust in practice;
- simple to operate;
- already supported by many existing IoT devices and gateways.

However, MQTT was designed as a generic messaging protocol, not as a native protocol for real-time decentralized energy systems. This is why OpenCEC should retain MQTT as a bootstrap implementation profile while also defining a longer-term protocol objective.

13.1. Alpha protocol objective

Beyond the MQTT profile retained for `0.1`, OpenCEC should explicitly target a more native communication protocol, here provisionally called `Alpha`.

The design intention of `Alpha` is to improve on generic message-broker usage by combining:

- a `Register / Publish / Subscribe` interaction model rather than a pure broker-topic abstraction;
- `UDP` as the primary transport substrate where low latency, low overhead, and local resilience are decisive;
- compact binary frames rather than verbose textual payloads;
- optimized payload schemas designed for electrical measurements, forecasts, prices, flexibility, and device capabilities;
- direct integration with a time-series history layer so that the protocol is not limited to current state dissemination but also carries native access to signal history.

The strategic point is not novelty for its own sake. The point is to move, over time, from an adapted IoT transport profile toward a protocol genuinely shaped for energy coordination.

In that perspective, `MQTT` should be understood as the practical bridge for the current draft, while `Alpha` is a long-term protocol objective for a more efficient and protocol-native OpenCEC stack.

13.2. Beyond MQTT: the OpenCEC Alpha Protocol

`Alpha` should be understood as a lightweight binary protocol designed specifically for distributed energy communities.

In simplified form, the contrast is the following.

- `MQTT`: broker-centered, topic-oriented, generic, and largely application-defined at payload level.
- `Alpha`: energy-native, capability-aware, history-aware, and designed around first-class electrical objects.

This does not mean MQTT is a mistake. It means that, if OpenCEC succeeds, later versions should move from a useful generic substrate toward a more explicit energy protocol.

13.2.1. Register / Publish / Subscribe model

`Alpha` should be based on a `Register / Publish / Subscribe` model.

`Register`

A device first declares itself and its capabilities to the local or community environment.

Typical declared objects may include:

- photovoltaic inverter;
- EV charger;
- battery;
- heat pump;
- water heater;
- meter;
- flexible load;
- local controller or gateway.

The registration object should later include fields such as:

- `device_id`;
- `energy_role`;
- `capabilities`;
- `power_range`;
- `storage_capacity`;
- `control_modes`;
- `forecast_capabilities`.

`Publish`

Devices then publish native energy signals rather than opaque application blobs. Typical signals include:

- production;
- consumption;
- available flexibility;
- storage state;
- forecast;
- local constraints;
- local availability or unavailability.

`Subscribe`

Devices subscribe directly to useful energy signals, for example:

- local energy abundance;
- shortage signal;
- dynamic price;
- CO2 signal;
- grid constraints;
- optimization requests.

The aim is to make the protocol itself closer to the language of an energy system rather than to the language of a generic message bus.

13.2.2. Native time-series memory

A fundamental difference between `Alpha` and a generic message transport is that `Alpha` should not be only a communication protocol. It should integrate a distributed temporal database logic.

Every important signal should be modelled together with:

- `timestamp`;
- `source`;
- `validity_period`;
- `confidence`;
- `history`;
- `forecast_horizon`.

In such an architecture, a device or service could ask protocol-native questions such as:

- what was the local price yesterday;
- what is the expected abundance tomorrow;
- what is my recent consumption history;
- what flexibility signal was active during a disputed period.

In other words, the protocol should manage not only energy messages, but also energy memory.

13.2.3. Binary optimized payloads

Energy signals are often small, frequent, repetitive, and strongly typed. For such objects, verbose textual encoding is not necessarily the best long-term fit.

`Alpha` should therefore explore:

- binary encoding;
- fixed or versioned schemas;
- compact numerical representation;
- low CPU usage;
- low bandwidth usage.

This is important if OpenCEC is to run not only on servers but also on:

- `ESP32`-class devices;
- smart meters;
- embedded controllers;
- appliances;
- low-power gateways.

13.2.4. UDP-based communication model

`Alpha` should explore `UDP` rather than assuming `TCP` by default.

The underlying reason is conceptual: energy control is not file transfer. In many situations, a fresh measurement is more valuable than an old delayed packet.

This leads to several design preferences:

- freshness over guaranteed delivery;
- sequence numbers;
- timestamps;
- automatic resynchronization;
- periodic state publishing.

Reliability should then be handled at the level of energy objects and protocol state, not only at the level of transport retransmission.

13.3. Long-term appliance interoperability target

In the long run, OpenCEC should aim at a world in which any electricity-producing or electricity-consuming device can:

- interpret a price or flexibility signal;
- expose its relevant capabilities;
- publish measurements and state changes;
- receive community or local control intents within explicit permissions;
- communicate through `Alpha`, or through a gateway that faithfully maps to `Alpha` semantics.

This target matters because a genuine energy protocol should not remain confined to servers and dashboards. It should progressively become understandable by inverters, batteries, EV chargers, heat pumps, water heaters, industrial loads, and other controllable assets.

For `0.1`, this is not yet a compliance requirement. `MQTT` remains the practical entry profile. But the architecture should already be written so that later versions can migrate from `MQTT` messages to more native `Alpha` exchanges without redesigning the whole semantic layer.

Future appliances should therefore become capable of expressing needs rather than merely exposing raw power states. Typical examples include:

- a washing machine able to say: `I need 2 kWh before tomorrow 07:00`;
- an EV able to say: `I need 60% battery before 08:00, optimize charging`;
- a water heater able to say: `I need 200 L of hot water available, choose the best energy window`.

The device expresses constraints and objectives. The community provides optimization signals, local price context, and admissible control envelopes.

13.4. Topic namespace

The canonical namespace for this draft is:

- `opencec/v0.1/{cec_id}/meter/{dp_id}/measurement`
- `opencec/v0.1/{cec_id}/forecast/{actor_id}`
- `opencec/v0.1/{cec_id}/allocation/{period}`
- `opencec/v0.1/{cec_id}/price/{period}`
- `opencec/v0.1/{cec_id}/flexibility/{asset_id}`

The explicit version segment is mandatory so that parsers can reject incompatible messages cleanly.

13.5. Message envelope

Every OpenCEC protocol message should expose at least:

- `protocol_version`;
- `message_type`;
- `cec_id`;
- `sender_id`;
- `message_id`;
- `timestamp`;
- `period` or `time_window` when relevant;
- `payload`;
- `signature` or verifiable integrity token.

Protected messages must also include the SIGL authorization references defined in the SIGL profile: credential, challenge, policy, and decision-receipt references, plus a delegation reference when applicable. The envelope should carry opaque references rather than a full credential where this reduces unnecessary disclosure.

The message identifier should be unique within the sender scope. Timestamps should use UTC and ISO 8601 formatting. Messages lacking a version identifier or timestamp should be rejected as non-compliant. A protected action without valid SIGL authorization evidence should likewise be rejected, except under a declared and logged local-safety fallback.

13.6. Confidential value voting

OpenCEC should eventually support a native protocol object for `confidential value voting`.

The purpose is to let participants attached to a `delivery point` express a scalar preference value without exposing that value publicly at participant level, while still allowing the community to compute a collective result.

This mechanism is especially useful when the community must choose among one-dimensional parameters or thresholds, for example:

- comfort or flexibility settings;
- investment priorities expressed on a numerical scale;
- local operating tolerances;
- community budget allocations;
- non-energy local choices that the community decides to organize through the same trusted infrastructure.

The decisive rule is that the collective output should be the `median` of submitted values.

This matters because the median:

- is robust to extreme values;
- minimizes aggregate absolute dissatisfaction in one-dimensional choice problems;
- remains interpretable to non-specialists;
- fits local democratic use cases better than average-based mechanisms in many situations.

13.6.1. Delivery-point basis

In this architecture, the voting right should be attached, by default, to the `delivery point` rather than to an abstract platform account.

This does not force all communities to adopt the same constitutional rule for vote weighting. But it provides a clear default anchor in a physical and auditable local reality: one active delivery point, one vote-bearing local participation unit, subject to the governance rules of the community.

13.6.2. Confidentiality requirement

Value voting should be confidential at the individual submission level.

Minimum expectations for a future voting object therefore include:

- authenticated eligibility of the voting delivery point;
- confidentiality of the submitted scalar value;
- auditability of the tally process;
- proof that the published result corresponds to the admitted aggregation rule;
- replay protection and deadline enforcement.

OpenCEC `0.1` does not define a full cryptographic voting scheme. But later versions should define protocol objects for secure submission, sealed storage or equivalent confidentiality protection, and verifiable publication of the median result.

13.6.3. Beyond electricity-only decisions

Although OpenCEC is rooted in electricity coordination, the same trusted local infrastructure may later support other community decisions.

Examples include:

- local service priorities;
- maintenance preferences;
- public-space equipment choices;
- local solidarity or resilience fund allocation;
- municipal or neighborhood questions that the community decides to treat through the same democratic channel.

This extension should remain governed by explicit local rules. The protocol may support the mechanism, but the legitimacy of each use remains a governance matter.

13.7. Security and replay protection

The protocol profile should provide:

- sender authentication;
- payload integrity;
- replay protection through message identifiers and timestamps;
- explicit handling of stale messages;
- audit logging sufficient to reconstruct a settlement dispute.

Replay protection does not require cryptographic novelty. It requires a clear rule for freshness windows and duplicate detection.

13.8. Delivery semantics

QoS should be selected by message family:

- measurements: at least once, with deduplication support;
- allocations and price vectors: at least once, retained until superseded;
- flexibility activation signals: profile-dependent, with explicit timeout handling.

Retained messages are useful for stateful topics such as current capabilities or current active price vectors. They should not be used as a substitute for historical archives.

13.9. Offline behavior

An implementation should define what happens when a participant, device, or PMO component is temporarily offline. Minimum expectations are:

- local buffering of critical outbound messages where feasible;
- local persistence of measurements, active signals, and relevant forecast objects within bounded storage limits;
- explicit stale-state marking on restored synchronization;
- resynchronization rules allowing delayed replay after prolonged disconnection;
- deterministic fallback behavior for settlement periods with incomplete data;
- audit visibility of missing or estimated values.

For a frugal edge-device reference profile, the protocol should remain workable on constrained hardware with limited memory, no advanced AI requirement, and long disconnected autonomy. A useful engineering target is the ability to operate asynchronously and retain enough local history and forecast context to cover outages on the order of `one month` before controlled resynchronization.

13.10. Capability discovery

Each implementation should expose discoverable capability metadata indicating, at minimum:

- supported protocol version;
- supported message families;
- supported temporal resolutions;
- supported signature or authentication schemes;
- optional features such as flexibility offers or inter-CEC roaming.

Capability discovery should later be extended so that devices can declare not only protocol support, but also economic and operational literacy, for example:

- ability to interpret a dynamic price signal;
- ability to respond to a local flexibility activation;
- local fallback mode if communication is lost;
- local buffering of short signal history;
- supported mapping between `MQTT` and `Alpha`.

13.11. Minimal JSON examples

Measurement:

```
{
  "protocol_version": "0.1",
  "message_type": "measurement",
  "cec_id": "cec-floirac-01",
  "sender_id": "meter-gw-17",
  "message_id": "m-2026-07-04T10:15:00Z-pdl-8842",
  "timestamp": "2026-07-04T10:15:00Z",
  "period": "2026-07-04T10:00:00Z/2026-07-04T10:15:00Z",
  "payload": {
    "dp_id": "dp-8842",
    "active_energy_kwh": 3.42,
    "direction": "consumption"
  },
  "signature": "base64:..."
}
```

Forecast:

```
{
  "protocol_version": "0.1",
  "message_type": "forecast",
  "cec_id": "cec-floirac-01",
  "sender_id": "actor-23",
  "message_id": "f-2026-07-04T11:00Z-actor-23",
  "timestamp": "2026-07-04T09:00:00Z",
  "payload": {
    "actor_id": "actor-23",
    "period": "2026-07-04T11:00:00Z/2026-07-04T12:00:00Z",
    "expected_consumption_kwh": 6.1,
    "expected_production_kwh": 0.0,
```

```
    "flexibility_up_kwh": 0.8,
    "flexibility_down_kwh": 0.4
  },
  "signature": "base64:..."
}
```


Allocation result:


```
{
  "protocol_version": "0.1",
  "message_type": "allocation_result",
  "cec_id": "cec-floirac-01",
  "sender_id": "pmo-1",
  "message_id": "a-2026-07-04T10:15Z",
  "timestamp": "2026-07-04T10:16:00Z",
  "payload": {
    "period": "2026-07-04T10:00:00Z/2026-07-04T10:15:00Z",
    "algorithm_id": "water-filling-v1",
    "allocations_kwh": {
      "person-A": 3.5,
      "person-B": 3.5,
      "person-C": 2.0
    }
  },
  "signature": "base64:..."
}
```


Price vector:


```
{
  "protocol_version": "0.1",
  "message_type": "price_vector",
  "cec_id": "cec-floirac-01",
  "sender_id": "pricing-engine-1",
  "message_id": "p-2026-07-04T10:15Z",
  "timestamp": "2026-07-04T10:16:10Z",
  "payload": {
    "period": "2026-07-04T10:00:00Z/2026-07-04T10:15:00Z",
    "currency": "EUR",
    "volume_component_eur_per_kwh": 0.08,
    "balance_component_eur_per_kwh": -0.01,
    "network_component_eur_per_kwh": 0.015,
    "forecast_component_eur_per_kwh": -0.005
  },
  "signature": "base64:..."
}
```


Flexibility offer:


```
{
  "protocol_version": "0.1",
  "message_type": "flexibility_offer",
  "cec_id": "cec-floirac-01",
  "sender_id": "battery-asset-9",
  "message_id": "flex-2026-07-04T12:00Z",
  "timestamp": "2026-07-04T09:10:00Z",
  "payload": {
    "asset_id": "battery-asset-9",
    "period": "2026-07-04T12:00:00Z/2026-07-04T13:00:00Z",
```

```
    "upward_kwh": 2.5,
    "downward_kwh": 1.5,
    "activation_deadline": "2026-07-04T11:45:00Z"
  },
  "signature": "base64:..."
}
```

13.12. Roadmap implication

The protocol roadmap can therefore be expressed in three broad stages:

- `OpenCEC 0.x`: MQTT-oriented implementation profile;
- `OpenCEC 1.x`: experimental `Alpha` protocol profile;
- `OpenCEC 2.x`: native appliance support for protocol-level energy interaction.

The long-term objective is that energy devices become first-class citizens of a decentralized energy Internet.

Open question: later versions should specify a normative JSON schema catalog, a binary frame catalog for `Alpha`, and equivalent mappings between `MQTT`, `Alpha`, and other possible transports.

14. SIGL Mobile Identity, Authorization, and Responsibility

OpenCEC adopts `SIGL` as its passwordless authorization profile for management actions and mobile interoperability. SIGL is an open-source, self-hostable challenge–response system using hardware-backed asymmetric keys: the private key remains in the secure hardware of the holder device, while the CEC or its trusted service verifies a signature made for one precise action.

SIGL does not replace the OpenCEC energy protocol. It binds a verified holder, an action, and an approval to an OpenCEC object. This allows the community to distinguish who requested an operation, which ACC or CEC accepted it, which policy permitted it, and which device finally applied it.

14.1. Mandatory use in OpenCEC management tools

Every OpenCEC management tool `MUST` use SIGL for protected operations. This includes participant portals, operator and support consoles, gateway configuration, meter and asset management, governance tools, settlement tools, and interfaces made available to a PMO, installer, auditor, DSO, or external service provider.

A proprietary account may provide a local interface, but it must not be the authoritative source of a right. The authoritative decision must be a SIGL-verified proof associated with an OpenCEC role, mandate, asset, delivery point, or federation agreement. An implementation must therefore be able to accept the same SIGL holder proof across compatible tools rather than forcing the participant to create a different password account for each tool.

14.2. Credential and responsibility profile

For OpenCEC, a `SIGL credential` is the association between a hardware-backed public key and a scoped community authorization. The authorization may identify a participant, legal entity, delivery point, EV, charge point, gateway, asset operator, PMO staff member, auditor, or service.

The credential record must contain at least:

- a non-secret credential and public-key reference;
- the issuing or registering CEC, ACC, or federation trust domain;
- a role or capability;
- the scope: CEC, delivery point, asset, charge point, data category, or service;
- validity and revocation information;
- any explicit delegate or mandate reference;
- a policy identifier defining the action conditions.

Credentials must be least-privilege and revocable. A maintenance provider may operate one inverter for a limited period; it must not acquire the right to read every household measurement or to approve financial settlement. A credential is an authorization for a stated responsibility, not a universal account or a claim to personal data.

For every consequential operation, OpenCEC must retain a `SIGL decision receipt`: the action description, challenge identifier, holder public-key reference, approval time, policy, relevant delegation, and resulting OpenCEC object identifier. The receipt supports responsibility allocation and dispute handling without placing a reusable secret or full personal identity in every energy message.

14.3. Human experience: approve, do not transcribe

The normal path must contain no reusable password, shared secret, or time-based code copied from one device to another. The service creates a short-lived, action-bound challenge; the SIGL app receives it; the holder sees the exact action and confirms locally using Face ID, Touch ID, Android biometric confirmation, or the device unlock. The app signs the approved challenge with its non-exportable key and the requester verifies the signature.

This flow has an important anti-phishing property: the mobile application verifies the service challenge before the holder approves it. A QR code may be used to pair a new device or to start a hand-off, but it must encode only a short-lived request or pairing reference. It is not a password and cannot on its own authorize an action.

The baseline neutral supports are:

- push approval for a registered iOS or Android device;
- a QR pairing or hand-off flow when a public terminal, gateway, or charge point has no personal keyboard;
- a deep link from a compatible OpenCEC tool to the SIGL app;
- a documented recovery and revocation procedure when a device is lost.

`NFC` may be offered as an additional local discovery or hand-off medium, but OpenCEC 0.1 must keep QR and deep-link flows as the universal baseline across iOS and Android.

14.4. ACC roaming and electric mobility

Electric mobility demonstrates why identity, authorization, and settlement must remain separate. When a member of ACC A arrives at a charge point operated by ACC B, the member does not log in to the charge point and does not receive a copied code. The charge point presents an action-bound request, typically by QR or deep link. The member approves on the SIGL app. ACC B verifies that the public key holds a currently valid `roaming-charge` authorization recognized under the ACC A–ACC B agreement.

The authorization proves only what ACC B needs: for example, that the holder may start a charge session, the allowable tariff or energy limit, and the settlement agreement reference. It does not require disclosure of the member's complete account, domestic consumption history, or unrelated credentials.

The charging flow is:

1. the charge point identifies itself, its ACC host domain, connector, available power, and current tariff or local constraint;
2. it creates a short-lived SIGL challenge bound to `start charging`, that charge point, connector, and session conditions;
3. the EV driver approves the displayed action in the SIGL iOS or Android app;
4. ACC B verifies the signature, credential scope, revocation status, and applicable ACC A–ACC B roaming policy;
5. the charge point starts the session and records the authorization receipt with the meter session;
6. at session end, ACC B issues signed metering and settlement evidence to the home and host accounting domains.

For high-impact situations, SIGL's native `M-of-N` approval can enforce an additional community sign-off. Suitable examples are changing the maximum roaming credit, releasing a blocked settlement, changing a charging-station trust anchor, or applying an exceptional control policy. It must not be imposed for ordinary low-risk charging starts, where it would harm usability.

14.5. Personal data access and GDPR-respecting sharing

SIGL is also the common access key through which each participant reaches their own OpenCEC data from the Internet. A participant must be able to use the SIGL mobile application to approve access to their measurements, allocations, invoices, charging sessions, flexibility history, mandates, and the list of active services or delegates that can access those data.

The data service must issue an action-specific challenge such as `read my charging sessions`, `export my allocation history`, or `share aggregated production data with a researcher until`

`2027-06-30`. Once approved, it returns only the data within the authorized scope. The service must record the access or export in the participant-visible activity history, including the requesting tool, purpose, data category, time, policy, and decision receipt reference.

A participant may delegate access to a trusted person or service, but the delegation must be explicit, minimal, time-bounded, and revocable. For example, a household member may view one delivery point, an accountant may download invoices, and a researcher may receive aggregated or pseudonymized data. None of these delegates receives a general right to the entire account merely because they can perform one legitimate task.

SIGL provides the proof of holder approval and the enforcement point for access; it does not itself create a lawful processing purpose. Each data operation must still declare its purpose, legal basis, retention period, controller, and recipients. OpenCEC tools must apply data minimization, selective disclosure, encrypted transport, and the relevant rights of access, rectification, portability, objection, and erasure. A biometric factor remains inside the device and must never be collected as CEC data.

The participant portal must offer, through the same SIGL-protected path:

- access to the personal data and operational records held about the participant;
- export in documented, machine-readable OpenCEC formats;
- view and revocation of active device keys, delegates, services, and data-sharing grants;
- a clear explanation of the purpose, retention period, and recipient of each active data flow;
- a channel to request correction, restriction, or erasure where applicable.

14.6. Protocol binding and offline behavior

Protected OpenCEC messages must carry, or reference, the SIGL authorization evidence needed to verify their origin and admissibility. The message envelope is extended with:

- `sigl_credential_ref`;
- `sigl_challenge_id`;
- `sigl_policy_id`;
- `sigl_decision_receipt_ref`;
- `sigl_delegation_ref`, where a holder acts for another person or entity.

The values may be opaque references. A broker, gateway, or foreign ACC must not receive the holder's full profile merely to verify a permitted action.

SIGL approval requires connectivity between the challenge issuer and the registered device. Therefore OpenCEC must not pretend that a disconnected charge point can obtain a fresh mobile authorization. A charge point may operate only under a declared local fallback, such as an already verified, short-lived authorization cache or a safety-oriented emergency rule. Every fallback must be bounded, logged, reconciled when connectivity returns, and never silently expanded into an unrestricted bypass.

14.7. DNS and mobile network privacy

DNS is not an identity mechanism and must not carry credentials. Mobile OpenCEC applications should use authenticated encrypted application transport and should support privacy-preserving resolver profiles such as DNS over HTTPS or DNS over TLS where the operating system permits. DNS configuration may be activated through an iOS/Android profile or an application deep link, but it must remain separate from SIGL credential issuance and authorization.

The architectural lesson is simple: DNS protects the path to a named service; SIGL proves approval for a named action. Both reduce attack surface, but neither substitutes for the other.

14.8. Open implementation and governance

SIGL deployments must be self-hostable or community-mandated, with published trust anchors, enrollment rules, revocation process, recovery process, challenge lifetime, and audit retention. A participant must be able to revoke a lost device and enroll a replacement without preserving an old password. The recovery procedure must be proportionate and may use community verification, an existing approved device, or an explicit multi-party governance process.

The OpenCEC compliance suite must test the same SIGL credential across at least two management tools and, for the mobility profile, between a home ACC and a host ACC charge point. Passing a test means that the authorization is interoperable, scoped, revocable, auditable, and usable from both iOS and Android reference applications.

15. SIGL Trust, Assurance, and Safety Boundary

This chapter refines `SIGL-Authorization-0.1`. It is **NORMATIVE** for protected management actions. SIGL proves approval of a defined action by a credential under a policy; it does not by itself establish civil identity, legal capacity, legal basis for processing, grid authorization, or regulatory authorization.

15.1. Canonical authorization evidence

For every protected action, the verifier must be able to resolve a versioned evidence object containing: credential identifier and public-key reference; issuer or registering trust domain; verifier; subject or pseudonymous holder reference; capability; resource scope; action; challenge identifier; nonce; issued-at and expiry time; policy identifier and version; delegation reference where relevant; decision time; signature algorithm identifier; signature; revocation status and time checked; and resulting OpenCEC object identifier.

The exact serialization is a **FUTURE WORK** item. Before a canonical serialization is published, implementations must expose an unambiguous documented mapping of these fields and must not claim wire-level interoperability solely from similar user interfaces.

15.2. Assurance levels and action classes

Each protected action must be classified before execution.

- `A0` public or non-consequential access: no SIGL decision is required.
- `A1` ordinary personal read or reversible preference: one valid scoped credential and an action-bound approval.
- `A2` consequential operational or financial action: A1 plus a short challenge lifetime, fresh revocation check, replay protection, and a participant-visible receipt.
- `A3` high-impact action: A2 plus explicit policy review and either a stronger recovery-resistant credential or a declared multi-party approval rule.

Starting an ordinary charge session is normally A2. Changing a trust anchor, a roaming credit ceiling, a settlement release, a governance rule, or an emergency-control policy is A3. A policy must not raise an ordinary action to A3 merely to create friction, and must not lower an A3 action for convenience.

15.3. Trust, revocation, recovery, and service actors

Each trust domain must publish its trust anchors, credential issuance authority, enrollment evidence, revocation endpoint or distribution rule, maximum challenge lifetime, clock tolerance, key-rotation procedure, recovery procedure, and incident contact. A verifier must reject an expired, revoked, malformed, replayed, or scope-inadequate credential. It must record an inability to determine revocation status and apply a published fail-closed or tightly bounded fail-safe policy according to the action class.

An automated service, gateway, or device must not impersonate a natural person. It may act under a separately issued service credential with a constrained capability, resource scope, validity, rate limit, and audit identity. A DSO, regulator, emergency responder, or other legally mandated actor must use a separately documented legal-access profile; this exception must be visible in the audit trail and cannot become a general operator bypass.

15.4. Offline, emergency, and platform boundary

No disconnected device may create a fresh SIGL approval. A local fallback is valid only if it states its pre-authorized scope, maximum duration, energy or financial ceiling, safety purpose, reconciliation rule, and participant notification rule. It must be distinguishable from an online authorization in every record.

`Hardware-backed` means that the private key is non-exportable according to the platform assurance attested by the implementation. A compliant implementation must declare the platform guarantee actually obtained; it must not assume that every iOS or Android device provides an identical assurance level. Biometric data remain local to the device and are never an OpenCEC credential attribute.

15.5. Minimum adversarial tests

The profile test suite must demonstrate rejection of: an expired challenge; a reused nonce; a revoked credential; a valid credential with insufficient scope; a delegation used after expiry; an altered action description; a substituted verifier; and a stale offline fallback. It must demonstrate successful revocation and recovery without retaining or reintroducing a reusable password.

16. Interoperability

An isolated CEC may be useful, but it cannot fully support mobility, roaming, federation, or vendor replacement. OpenCEC therefore treats interoperability as a constitutive requirement rather than as a late convenience feature.

The most useful analogy is again the distinction between a local area network and a wide area network. A single CEC behaves like an energy LAN: it coordinates local identities, measurements, allocations, prices, and service relations. A federation of interoperable CECs behaves like an energy WAN: rights, proofs, and settlements can travel across institutional boundaries.

The point is not that electrons themselves travel with a user identity. They do not. What travels are energy rights, measurements, settlement statements, and proofs of equivalent protocol treatment.

16.1. Interoperability objects

Interoperability between communities should minimally address:

- identity federation;
- SIGL credential verification, revocation, and action receipts across communities;
- authenticated exchange of metering or settlement evidence;
- roaming agreements between participating communities or PMOs;
- trust registries for keys, versions, and recognized operators;
- dispute resolution procedures;
- data export and migration paths.

16.2. Energy nomadism

Energy nomadism refers to the continuity of participant rights when a member interacts with another compatible community or another physical location. The participant should not have to restart from zero in every territory if protocol compatibility exists.

This does not imply full portability of every local benefit. Some rights remain inherently local. But the protocol should maximize continuity where meaningful:

- identity continuity;
- compatible settlement records;
- visibility of price components;
- portability of auditable consumption or flexibility history.

This leads to a broader principle of energy citizenship: membership should be able to follow the person, not only the meter, wherever protocol-compatible conditions allow it.

16.3. Electric mobility

Electric vehicles are a central use case because they are simultaneously:

- mobile loads;
- mobile storage assets;
- potential flexibility resources.

If a participant charges a vehicle inside a foreign but compatible CEC, OpenCEC should aim to preserve as much of the home logic as possible, without pretending that local physical constraints disappear. The host community still applies its own network and operational constraints, but the roaming process should allow intelligible settlement between home and host domains.

16.4. Roaming model

At a minimum, a roaming interaction should support:

- SIGL verification of a scoped `roaming-charge` credential;
- acceptance of a roaming agreement;
- exchange of charging or consumption measurements;
- production of a settlement statement;
- attribution of applicable local and home-community adjustments.

16.5. CEC federation protocol

Inter-community roaming should be formalized as a federation problem rather than an informal bilateral workaround.

Relevant use cases include:

1. `Secondary home`: a member produces in one CEC and temporarily consumes in another.
2. `Electric mobility`: a vehicle charges in another CEC while retaining community identity and settlement continuity.
3. `Energy citizenship`: rights and permissions are partially attached to the member identity, not exclusively to one fixed meter.

One possible protocol object is an `Energy Passport`:

```json
{
  "member_id": "member-204",
  "home_cec": "cec-alpine-01",
  "permissions": ["roaming-charge", "read-price-vector"],
  "settlement_rules": "default-home-cec-v1",
  "sigl_credential_ref": "opaque-public-key-reference",
  "sigl_policy_id": "roaming-charge-v0.1"
}
```

16.6. Federation model diagram

The federation logic can be represented as follows.

CEC A members assets prices settlement rules	federation	**Trust and interoperability layer** identity federation keys and signatures roaming permissions audit proofs settlement evidence	federation	**CEC B** members assets prices settlement rules

Home member identity	produces	**Energy passport**	authorizes	**Roaming consumption or charging event**

Host measurements	feed	**Settlement statement**	returns to	**Home and host accounting domains**

The important point is that federation does not require one giant centralized community. It requires compatible local communities able to exchange proofs, rights, and settlement objects under explicit public rules.

16.7. Institutional consequence

Interoperability is not only technical. It requires public rules for trust and conflict handling. Two communities may use the same message schemas and still fail to interoperate if:

- one refuses export of participant data;
- one uses opaque service margins;
- one cannot produce auditable settlement proofs;
- one changes algorithmic rules without version visibility.

That is why replaceability, auditability, and explicit pricing are interoperability requirements, not merely governance preferences.

Open question: later versions should define a more formal roaming profile for EV charging and cross-community settlement.

17. Relation to Existing Energy Communication Standards

OpenCEC should not be misunderstood as an attempt to replace every existing technical protocol used in energy systems, building automation, or connected devices.

Its intended role is higher-level and more specific: to provide a semantic and economic coordination layer for citizen-oriented energy communities.

17.1. Positioning principle

Most existing standards answer one of the following questions:

- how to control an industrial device;
- how to expose telemetry;
- how to automate a substation;
- how to signal demand response;
- how to connect appliances;
- how to supervise EV charging;
- how to exchange generic messages.

OpenCEC answers a different question:

how can autonomous actors in a `CEC` coordinate allocation, pricing, flexibility, auditability, and governance under shared public rules?

17.2. IEC 61850

Objective:

- substation automation;
- industrial power-system communication;
- structured information models for electrical equipment.

Strengths:

- highly relevant for professional grid automation;
- rigorous and mature in industrial settings;
- strong semantic discipline for utility environments.

Limitations for OpenCEC:

- not designed for citizen-facing economic coordination;
- not centered on community governance or democratic allocation;
- too close to utility automation logic to directly solve the CEC protocol problem.

Relationship with OpenCEC:

OpenCEC should not replace `IEC 61850`. It sits elsewhere in the stack and may, in some cases, consume abstractions derived from utility-grade systems.

17.3. OpenADR

Objective:

- demand response signaling between utilities, aggregators, and customer-side systems.

Strengths:

- focused on operational signals;
- relevant for flexibility and demand response;
- already connected to utility-side use cases.

Limitations for OpenCEC:

- fundamentally utility-to-device oriented;
- not a community governance framework;
- does not define the wider economic and democratic architecture of a CEC.

Relationship with OpenCEC:

OpenCEC may interoperate with `OpenADR`-like signals where relevant, but it addresses a broader and more symmetric coordination problem.

17.4. Matter

Objective:

- interoperability among smart-home devices and ecosystems.

Strengths:

- useful for appliance-level interoperability;
- relevant for home devices and local control;
- growing ecosystem visibility.

Limitations for OpenCEC:

- not designed as an energy-market or community protocol;
- does not define auditable community price logic;
- does not by itself solve settlement, allocation, or governance.

Relationship with OpenCEC:

Matter may become one useful device-facing substrate under or beside OpenCEC, especially for appliance interaction.

17.5. OCPP

Objective:

- communication between EV chargers and charging-management systems.

Strengths:

- highly relevant for EV infrastructure;
- already industrially established in its domain;
- useful for charging supervision and management.

Limitations for OpenCEC:

- domain-specific to charging infrastructure;
- not a general community-energy coordination layer;
- does not define wider multi-asset economic semantics.

Relationship with OpenCEC:

OpenCEC may sit above `OCPP` when EV charging participates in CEC-level optimization.

17.6. Modbus

Objective:

- field-level industrial communication.

Strengths:

- simple and widespread;
- useful for direct integration with meters, relays, and equipment;
- practical for low-level telemetry and control.

Limitations for OpenCEC:

- weak semantic richness by itself;
- not suitable as a community protocol;
- does not represent pricing, governance, or allocation meaning.

Relationship with OpenCEC:

`Modbus` remains a field protocol. OpenCEC remains a coordination protocol.

17.7. MQTT

Objective:

- generic lightweight messaging for distributed systems and IoT.

Strengths:

- excellent bootstrap transport;
- simple deployment model;
- broad device and software support.

Limitations for OpenCEC:

- not an energy model;
- leaves semantics to applications;
- no native economic meaning;
- no native time-series memory.

Relationship with OpenCEC:

This is why MQTT is retained in `0.1` as a practical transport profile while OpenCEC keeps a longer-term objective of more native energy protocol forms.

17.8. Position of OpenCEC

OpenCEC should therefore be understood as:

- not a substation protocol;
- not only a fieldbus;
- not only a smart-home interoperability framework;
- not only a demand-response signal stack;
- not only an EV charging protocol;
- not only a generic message broker profile.

OpenCEC sits above those layers when needed. Its role is to standardize the semantic and economic coordination layer for energy communities.

18. Algorithm Arena

OpenCEC should not claim that one final, perfect algorithm has already been found for every community-energy problem. The role of the specification is to create conditions under which algorithms can be compared, criticized, replaced, and improved without losing interoperability.

This is one of the strongest differences between a scientific protocol and a proprietary platform. A proprietary platform asks users to trust hidden optimization. OpenCEC should allow researchers, laboratories, PMOs, and developers to propose better mechanisms in public.

The central principle is therefore:

OpenCEC must be able to be improved by better algorithms without being captured by any single vendor or political authority.

18.1. OpenCEC algorithm competition framework

The fair-price algorithm and related coordination algorithms are not fixed forever. The specification defines the arena in which algorithms can be evaluated, replaced, or rejected.

The arena `MUST` support:

- public datasets where legally and ethically possible;
- historical replay of real or anonymized CEC operations;
- synthetic CEC scenarios;
- adversarial tests;
- reproducible benchmarks.

18.2. Core components of the arena

The algorithm arena should include at least:

- anonymized datasets;
- shared simulators;
- benchmark scenario catalogs;
- public leaderboards where appropriate;
- reproducibility requirements;
- challenge tracks for specific problems;
- bug bounty and bias bounty processes.

18.3. Problem families

The initial families of problems include:

- volume allocation;
- price discovery;
- flexibility coordination;
- forecasting;
- network-aware optimization;
- settlement verification and anomaly detection.

18.4. Evaluation criteria

Algorithms proposed inside the OpenCEC ecosystem should be compared through explicit criteria such as:

- energy efficiency;
- producer revenue;
- consumer savings;

- grid impact;
- storage usage;
- equity;
- explainability;
- robustness to missing or noisy data;
- resistance to manipulation;
- privacy impact;
- computational cost;
- regulatory compatibility.

No single criterion is sufficient. A highly efficient algorithm that is impossible to explain, easy to manipulate, or too expensive to compute may be a poor protocol candidate.

18.5. Reproducibility discipline

Any algorithm proposed as OpenCEC-compatible should be accompanied by:

- a written description;
- input and output definitions;
- versioned code or pseudo-code;
- dataset assumptions;
- benchmark results reproducible by third parties.

This requirement is essential to prevent scientific language from masking non-reproducible vendor claims.

18.6. Replacement rule

A new algorithm `MAY` replace an older one only if comparative simulations and published benchmarks demonstrate an improvement on clearly stated criteria. The protocol defines the competition framework, not the permanent winner.

18.7. OpenCEC test networks

Safe innovation requires multiple validation environments.

- `Simulation sandbox`: no real energy and no economic consequence; based on historical datasets and synthetic scenarios.
- `Shadow mode`: connected to real CEC data, but producing recommendations only and no binding settlement effect.
- `Production mode`: validated algorithms with real settlement and operational consequences.

An algorithm `SHOULD` progress through these environments before being used in production.

18.8. Incentive layer

The arena should support not only performance competition but also criticism and red-teaming. Useful incentives include:

- public recognition for better-performing algorithms;
- bounties for discovering manipulation vectors;
- bounties for confidentiality leaks;
- bounties for instability under edge conditions;
- bounties for unfair bias against classes of participants.

This can be understood as an `Algorithm Bug Bounty` model open to researchers, universities, companies, and citizens.

Open question: later versions should define how algorithm modules are proposed, reviewed, adopted, deprecated, or sandboxed without fragmenting interoperability.

19. Community Energy Digital Twin and Artificial Intelligence

19.1. Community Energy Digital Twin

An OpenCEC community should progressively be able to maintain a `Community Energy Digital Twin`: a structured computational representation of the community's relevant energy reality.

This twin should include, at least conceptually:

- production assets;
- consumption profiles;
- storage assets;
- flexible loads;
- weather forecasts;
- relevant grid constraints;
- historical measurements;
- community rules and algorithm parameters.

The purpose is not decorative digitalization. The purpose is to create a simulation-grade object that allows the community to test decisions before locking them into investment or operating practice.

19.1.1. Uses of the digital twin

The digital twin can support:

- algorithm comparison;
- investment planning;
- scenario simulation;
- anomaly diagnosis;
- forecast evaluation;
- stress testing under extreme conditions;
- preparation of interoperability pilots.

Example:

Before installing `1 MW` of additional photovoltaic capacity, the community may simulate:

- expected collective self-consumption rate;
- value of added battery capacity;
- EV flexibility contribution;
- likely network impact;
- distributional effects between participant categories.

In this sense, the digital twin becomes the bridge between abstract protocol rules and concrete local decisions.

19.2. Artificial Intelligence in OpenCEC

Artificial intelligence may become useful in OpenCEC, but its role must remain disciplined.

The core principle is simple:

AI may optimize. AI must not govern.

19.3. Useful roles for AI

AI or advanced statistical learning may help with:

- forecasting production and demand;
- anomaly detection;

- flexibility estimation;
- maintenance prediction;
- investment optimization;
- behavioral assistance for participants;
- simulation acceleration inside the digital twin.

These are valuable functions because they improve decision quality without requiring AI to define the constitutional rules of the community.

19.4. Hard limits

OpenCEC should state clear boundaries.

AI `MUST NOT`:

- hide pricing rules behind opaque outputs;
- replace public allocation logic with unauditable heuristics;
- capture governance through technical opacity;
- deprive participants of explanation and contestation;
- become the de facto sovereign of the community.

An implementation may use AI inside subsystems, but the normative protocol layer should remain explainable and auditable.

19.5. Explainable energy AI

The appropriate orientation is therefore `explainable energy AI`.

This means:

- forecasts may be probabilistic, but their error and confidence should be visible;
- anomaly scores should be interpretable enough to support human review;
- optimization proposals should remain challengeable;
- collective rules should remain authored by governance, not by model drift.

OpenCEC should welcome strong forecasting and optimization tools, but only under the condition that they strengthen, rather than dissolve, democratic intelligibility.

20. Cybersecurity, Privacy, and Social Adoption

20.1. Cybersecurity threat model

OpenCEC is a cyber-physical coordination system. A failure is not only a software inconvenience. It may affect settlement, automation, trust, and local infrastructure behavior.

The threat model should therefore include at least:

- fake production or consumption data;
- price manipulation;
- device hijacking;
- denial of service;
- replay attacks;
- privacy leakage;
- malicious or compromised gateways;
- corrupted historical archives.

One practical principle should remain visible throughout the architecture:

a hacked washing machine should not destabilize a CEC.

20.2. Security principles

To reduce those risks, OpenCEC should move toward:

- durable device identity;
- SIGL hardware-backed mobile approval for protected management actions;
- cryptographic signatures or integrity proofs;
- least-privilege access control;
- zero-trust assumptions between components;
- anomaly detection for impossible or suspicious states;
- local fallback modes when upstream trust is degraded;
- segmented architectures limiting lateral movement after compromise.

Cybersecurity is therefore not only a matter of encryption. It is also a matter of containment, recoverability, and graceful degradation.

SIGL is the mandatory authorization enforcement point for OpenCEC management tools. A protected data read, configuration change, asset-control intent, credential enrollment, delegation, or export must be bound to an action-specific challenge and retained decision receipt. Local biometrics may unlock a private key on the holder device; they must never be transmitted to the CEC as a shared authentication secret.

20.3. Privacy and GDPR orientation

SIGL approval is evidence of an action; it is not, without further analysis, the lawful basis for every processing operation. Each controller or joint-controller arrangement must document the processing purpose, legal basis, recipients, retention, access controls, transfers, and rights-handling path. A consent-like interface must not be used where the relevant processing is necessary for a contract, legal obligation, vital interest, or another legally applicable basis. The participant must be able to distinguish operational necessity from optional sharing.

Energy data are deeply revealing.

Fine-grained records may expose:

- presence at home;

- occupancy rhythms;
- appliance usage;
- mobility habits through EV charging;
- heating patterns;
- broader lifestyle information.

For this reason, OpenCEC should adopt a privacy-by-design orientation compatible with European data-protection logic.

Core principles include:

- data minimization;
- purpose limitation;
- role-based access;
- local filtering where feasible;
- explainability of retention and sharing policies.

SIGL operationalizes those principles at the access boundary. Each participant should reach their own data from the Internet through a SIGL-approved, action-specific request, and should see the same audit history that operators see for personal-data access, export, or sharing. A delegated service may receive only the fields, purpose, and duration covered by its revocable SIGL authorization. The system must not treat a successful login as blanket consent for all present and future uses of energy data.

The participant-side gateway has an important role here. A local device can filter, aggregate, or delay some data before community transmission, reducing the temptation to equate intelligence with surveillance.

The community needs aggregate intelligence, not domestic overexposure.

20.4. Social adoption

No protocol, however elegant, creates a successful CEC by itself.

Social adoption depends on:

- understandable signals;
- visible benefits;
- trust in operators and rules;
- simple participation paths;
- low-friction onboarding;
- credible grievance and explanation mechanisms.

The central principle is that the citizen should not become an energy trader.

Automation should manage complexity. Humans should define values, permissions, and collective priorities.

If a community requires every participant to behave like a market specialist, it will exclude most citizens and reproduce technocratic inequality under green language.

This is why OpenCEC must remain demanding in protocol design while remaining humane in participation design.

20.5. Hardware ecosystem roadmap

The future compatible hardware ecosystem should gradually include:

Generation assets:

- PV inverters;
- wind turbines;
- hydro turbines where relevant.

Storage assets:

- stationary batteries;
- EVs.

Flexible loads:

- heat pumps;
- water heaters;
- washing machines;
- HVAC systems;
- industrial or tertiary flexible loads where relevant.

The key change is semantic.

Old world:

- turn device on;
- turn device off.

OpenCEC world:

- the device declares a need;
- the device declares flexibility;
- the device declares constraints;
- the community returns admissible coordination signals.

This is one of the clearest ways in which OpenCEC moves beyond command-and-control device logic toward protocol-native cooperation.

20.6. Implementation roadmap

One possible implementation roadmap is:

- `2026`: `OpenCEC 0.x`, MQTT implementation, first pilot communities;
- `2027`: `Alpha` prototype, stronger algorithm arena, workshop-driven consolidation;
- `2028`: European interoperability pilots;
- `2030`: broader native appliance support.

This roadmap is indicative rather than binding, but it provides a credible industrial horizon.

21. Reference Implementation

BoxEnergie may serve as an early reference implementation for parts of the OpenCEC stack, but OpenCEC should remain vendor-neutral. The reference role is useful only if it accelerates understanding and testing without capturing the specification.

The protocol layer and the implementation layer should therefore remain clearly separated. OpenCEC defines interoperable rules and message semantics. BoxEnergie, or any other operator, may implement these rules through software, hardware integration, supervision, or maintenance services.

BoxEnergie should be understood as a reference hardware implementation in a role comparable to early Internet routers: useful, practical, and historically important, but never identical to the protocol itself.

21.1. Normative boundary

An OpenCEC-compliant PMO coordinates; it does not buy and resell electricity.

This sentence captures the core boundary. A PMO may operate services, deploy gateways, maintain assets, provide support, or invoice explicit subscriptions. It should not hide its remuneration inside an opaque kWh spread.

A company `MAY` sell services. A company `MUST NOT` own the rules.

A PMO `MAY` use OpenCEC. A PMO `MUST` remain replaceable.

A BoxEnergie device `MAY` implement OpenCEC. A BoxEnergie device `MUST NOT` be required for compliance.

21.1.1. Distinction between CEC and supplier

OpenCEC should not be confused with the creation of a new local supplier category.

A conventional supplier:

- manages procurement and resale;
- arbitrates offers commercially;
- captures value through the supply interface;
- may remain structurally opaque to final users.

A CEC, as understood in this specification:

- coordinates local or community energy relations;
- structures allocation and cooperation rules;
- makes service layers separable from energy exchange;
- creates space for collective governance rather than commercial dependence.

This distinction is decisive for implementation choices. If BoxEnergie or any other operator were to hide its service remuneration inside the energy exchange itself, the implementation would drift back toward supplier logic and away from the OpenCEC philosophy.

21.2. Functional role of a reference implementation

A reference implementation is useful because it can provide:

- hardware integration;
- local autonomy;
- offline operation;
- measurement;
- automation;

- resilience;
- maintenance workflows;
- software deployment patterns;
- supervision interfaces;
- practical examples of message exchange;
- early compliance tests.

It must also provide SIGL reference clients for iOS and Android, plus an equivalent administration path for desktop operators. The clients should hold non-exportable device keys, show the precise action before approval, support push approval and QR/deep-link hand-off, and expose device revocation and recovery without reverting to a permanent password.

21.3. Reference hardware sobriety profile

The reference implementation should remain plausible on modest embedded hardware. A useful target profile is a participant-side gateway with computing power in the class of an `ESP32-S3`, with limited memory and without assuming a dedicated on-device AI accelerator or heavy local AI workload.

This point matters because OpenCEC should not quietly assume datacenter-grade resources at the edge. The protocol should remain deployable on inexpensive, frugal, and electrically sober hardware.

The reference hardware profile should therefore prioritize:

- asynchronous operation;
- deterministic local control logic;
- compact message handling;
- bounded memory use;
- selective local persistence;
- graceful degradation under connectivity loss.

The purpose of the edge device is not to run a large intelligence stack in isolation. Its purpose is to remain a reliable cyber-physical gateway between the electrical panel, local assets, and the community coordination layer.

21.4. Mixed intelligence architecture

The OpenCEC architecture should not assume that all intelligence sits in one remote cloud or, conversely, that every local device is fully autonomous. A more robust target is a mixed architecture in which intelligence exists both at community-server level and at participant-device level.

21.5. From cloud control to distributed energy intelligence

OpenCEC should explicitly reject two symmetrical extremes.

`Extreme A: fully centralized cloud control`

This model creates obvious risks:

- dependency on one operator;
- privacy exposure;
- single point of failure;
- fragile continuity in case of outage or disconnection;
- weak local autonomy.

`Extreme B: fully isolated local devices`

This opposite model also remains insufficient:

- no collective optimization;

- no community-level price coordination;
- no shared historical view;
- no coherent interface with DSOs, TSOs, aggregators, or settlement actors;
- no serious federated governance.

OpenCEC should therefore be understood as a hybrid intelligence model rather than as either a cloud monopoly or a collection of disconnected gadgets.

Using BoxEnergie vocabulary only as a reference archetype, this can be described as:

- a `maxi-boxenergie`, or community server, responsible for community-wide coordination, historical aggregation, pricing, allocation, supervision, and interconnection with external actors;
- a `mini box energie`, or participant-side device, responsible for local measurement capture, device orchestration, local automation, fallback behavior, and direct interaction with the household electrical environment.

This split is desirable because some decisions require community-wide visibility, while others require millisecond or second-level local reaction, privacy-preserving arbitration, or operation during upstream outages.

21.5.1. Mini / Maxi architecture diagram

Household assets PV, battery, EV charger, heat pump, loads	->	**Mini Box / Energy Edge Gateway** local measurement, filtering, automation, offline mode	->	**Maxi Box / Community Energy Node** history, pricing, allocation, supervision, federation

Community Energy Node	bidirectional link	**DSOs, TSOs, aggregators, other CECs**

For the participant-side device, this architecture should remain compatible with a constrained embedded profile:

- no assumption of large-model AI inference on device;
- memory budgets consistent with low-cost embedded hardware;
- asynchronous event processing rather than heavy continuous recomputation;
- durable local storage sufficient for prolonged disconnected operation.

21.6. Why a participant-side device is indispensable

A physical device linking the electrical panel to the Internet gateway should be considered structurally important for serious CEC operation.

The reasons are practical:

- the electrical panel is where measurements, contactors, protections, and controllable circuits become physically actionable;
- many useful assets are local and heterogeneous: inverter, battery, EV charger, water heater, HVAC, relay logic, submeters;
- local fallback remains possible even if the upstream network or central server is temporarily unavailable;
- price or flexibility signals become operational only when they can be translated into local action;
- latency, resilience, and cyber-physical safety are better handled close to the equipment.

It should also be capable of retaining operational memory while disconnected. In a reference profile, the participant-side gateway should be able to keep a significant local record of measurements, active signals, and relevant short-term forecasts for a long outage window, for example on the order of `one month`, and then resynchronize cleanly when connectivity returns.

Without such a device, a CEC risks remaining a purely accounting community rather than a real coordination system able to act on consumption, production, storage, and declared flexibility.

The Internet analogy is useful here. A computer alone did not create the Internet. It required network cards, modems, routers, and a protocol stack. Electricity requires a similar transition.

Today, many electrical assets are connected to wires but not to an energy information network. The electrical panel is still largely blind to community signals, dynamic prices, and local optimization context. A participant-side gateway is therefore the functional equivalent of an energy router: it connects electrons, measurements, economic signals, and automation.

21.7. Why a community energy server is indispensable

Symmetrically, a dedicated community or municipal energy server should also be treated as a core architectural component.

Its role is not to centralize ownership of energy. Its role is to centralize the community functions that require shared visibility and common audit:

- historical storage of measurements, forecasts, allocations, and prices;
- execution of allocation and price-discovery algorithms;
- publication of common signals;
- participant and asset registry;
- audit trail and replay of disputes;
- interface with PMO functions, DSOs, TSOs, aggregators, or external service providers;
- federation with other CECs.

In short, the participant-side device makes the protocol physically actionable, while the community server makes it collectively intelligible and auditable.

21.8. Server security, confidentiality, and local data sovereignty

The community-side server should not be treated as a simple convenience host. It is the custodian of economically sensitive, operationally sensitive, and civically sensitive information.

Minimum architectural expectations should therefore include:

- authenticated administrative access;
- SIGL credential verification, action-bound challenge approval, revocation checks, and decision receipts;
- strong separation between participant roles, operator roles, and audit roles;
- encrypted communications;
- signed or integrity-protected critical protocol objects;
- tamper-evident logs for allocation, pricing, and settlement-relevant events;
- backup and recovery procedures;
- explicit incident-response procedures.

Confidentiality is equally important. A CEC server may hold fine-grained information about household routines, heating behavior, charging habits, production curves, flexibility margins, and local vulnerabilities. Such information should not be casually exposed to remote service providers, data brokers, or non-essential commercial analytics layers.

For that reason, OpenCEC should prefer:

- local or community-controlled hosting where feasible;
- data minimization for exported interfaces;
- role-based access control;
- explicit retention policies;
- participant visibility into what data are stored, for how long, and for which purpose.

This leads to a broader principle of `local data sovereignty`. The community should remain politically and technically capable of controlling where its operational data are stored, who can access them, and under which mandate they can be transferred outside the local governance perimeter.

Local sovereignty does not require isolation from the wider world. A CEC may still federate with external actors, regulators, DSOs, TSOs, researchers, or service providers. But such exchanges should remain explicit, limited, auditable, and reversible.

An OpenCEC-compatible server should therefore make it possible to:

- host primary operational data locally or under community mandate;
- export only the minimum required data to outside actors;
- document every external data interface;
- revoke or change external service providers without losing community history;
- preserve participant rights over access, explanation, and contestation.

The server must expose a SIGL-protected participant data interface. From an Internet-connected compatible tool, a member should be able to approve access to their own data, export it in documented formats, inspect active delegates and sharing grants, and revoke them. Each access or export must be reflected in a participant-visible audit trail with purpose, recipient, data category, and retention information.

21.9. Open implementation principle

BoxEnergie should not be interpreted as mandatory hardware. OpenCEC defines a role, not a brand monopoly.

That role may be described generically as an `Energy Edge Gateway` on the participant side and a `Community Energy Node` on the community side.

Any manufacturer or implementation actor may build such components. Compliance should depend on:

- protocol support;
- security;
- interoperability;
- exportability of data and history;
- replaceability;
- not on brand identity.

21.10. Protocol consequence

This mixed architecture reinforces the protocol direction proposed in this document.

- In the short term, the participant device and the community server may communicate through `MQTT`.
- In the longer term, both should be able to communicate through `Alpha`.
- The participant device should progressively become capable of understanding protocol-native price and flexibility signals.

- The community server should progressively become capable of serving both current state and time-series history through the same protocol family.

This is one of the reasons why transport design cannot be reduced to generic IT convenience. OpenCEC is ultimately a cyber-physical coordination layer, and its protocol evolution should reflect that reality.

21.11. Explicit service model

An implementation may bill explicit services, for example a subscription such as `6 EUR/month/DP`, provided that:

- the fee is visible as a service fee;
- the fee is not hidden inside the energy exchange price;
- the community can compare the fee with alternative operators;
- exported data remain usable if the operator is replaced.

21.12. Replaceability obligation

No implementation should become the owner of participant history by technical lock-in. An OpenCEC-compatible implementation should therefore support:

- export of metering and allocation data;
- export of price vectors and settlement records;
- documented interfaces;
- migration tests toward another implementation.

OpenCEC != BoxEnergie.

Open question: later versions should define a formal compliance suite proving replaceability and message-level interoperability.

22. Greenwashing, Semantic Integrity, and Citizen Protection

This chapter defines anti-greenwashing requirements for OpenCEC and clarifies that key public-interest terms must correspond to auditable realities rather than marketing language.

22.1. Problem statement

In the energy field, much of the public confusion comes from the inflationary use of flattering words. Projects may present themselves as green, local, citizen-based, shared, or democratic without those qualifiers corresponding to tangible effects for the people concerned.

OpenCEC should make explicit that these words do not have a decorative function in the specification. They have normative value. Their use should be justified by precise, measurable, and verifiable criteria.

22.2. General anti-greenwashing principle

A flattering term should not be used in an OpenCEC document, in an interface linked to the protocol, or in implementation communication unless its real meaning can be demonstrated.

The burden of proof should be operational rather than rhetorical:

- documented governance rights;
- measurable local economic effects;
- explicit allocation rules;
- auditable service pricing;
- traceable physical or accounting links with community assets.

This requirement also applies to organizations and project families, not only to product brochures. A structure may present itself as territorial, cooperative, or citizen-oriented and still fail the OpenCEC standard if the material link between language and participant benefit remains too weak, too delayed, or too opaque.

22.3. Terms requiring strict definition

22.3.1. Green

The term `green` must not merely indicate the presence of renewable generation in the background of a project.

They should only be used when at least the following are documented:

- the physical energy assets involved;
- the renewable share actually attributable to the community arrangement;
- the lifecycle and maintenance obligations of the assets;
- the environmental limits or trade-offs of the project;
- the absence of misleading double counting in guarantees, claims, or accounting.

In other words, a project is not green because it borrows the symbolic vocabulary of transition. It must demonstrate a materially improved environmental profile.

22.3.2. Local

The term `local` is often used abusively. A project is not local merely because it is visible from the territory, because it is physically implanted there, or because it funds a few side activities.

In OpenCEC, a project should not be qualified as local unless an identifiable share of value actually returns to the relevant territory in a traceable form, for example:

- bill reduction for local participants;
- economic rights linked to locally situated assets;

- real decision capacity for local actors;
- reinvestment into local infrastructure;
- an objectively demonstrable improvement in local resilience or flexibility.

The term `local` must therefore be visible in citizens' bills, assets, and governance rights, not only in the geography of the project.

22.3.3. Citizen

The term `citizen` cannot designate a merely abstract possibility to participate.

It should require:

- open or clearly governed access conditions;
- non-purely symbolic participation rights;
- understandable information on risks and returns;
- capacity for members to influence major parameters or representatives;
- absence of hidden asymmetry that reserves effective control to a commercial operator.

If citizens only finance, but do not understand, govern, or benefit in a meaningful way, the term should be considered misleading.

22.3.4. Sharing

The term `sharing` implies more than a narrative of proximity. It requires that a resource, a value stream, or an advantage is actually distributed according to an explicit rule.

In OpenCEC, a project should not claim `sharing` unless it specifies:

- what is shared;
- among whom;
- by which algorithm or contractual rule;
- with which measurement basis;
- with which auditable consequence on bills, revenues, or rights.

Absent these elements, `sharing` remains a narrative gesture rather than a protocol fact.

22.3.5. Democracy

The term `democracy` is probably the most demanding. It cannot be reduced to the mere existence of a formal general assembly or an occasional consultation.

In OpenCEC, democracy implies at least:

- clearly defined voting rights;
- intelligible information before decision;
- genuinely open decision objects;
- traceability of modifiable parameters;
- control over rules, not only over persons.

This is especially important for algorithmic systems. A project cannot claim democratic legitimacy if the essential allocation or pricing rules remain opaque, proprietary, or non-modifiable in practice.

22.4. Economic materiality test

Each of the terms above should be subjected to an economic materiality test.

The core question is simple: what concrete difference does this claim make for a participating citizen?

Possible evidence includes:

- reduced annual electricity expenditure;
- measurable remuneration or dividend linked to an identified asset;
- explicit ownership share in infrastructure;
- predictable access to flexibility revenues or collective savings;
- enforceable governance rights with documented decisions.

If the citizen cannot identify the economic, organizational, or decision-making substance of the claim, the term should not be used.

22.5. Anti-greenwashing indicators

Several warning signals should trigger heightened scrutiny:

- the public narrative is much more precise than the technical or governance documentation;
- territorial communication is strong but participant-level bill effects remain absent or indeterminate;
- citizen investment is advertised before the corresponding asset rights, maintenance logic, or allocation logic are made explicit;
- "sharing" is emphasized while no protocol-level allocation rule is inspectable;
- "democracy" is claimed while essential parameters remain vendor-defined, financially opaque, or operationally unreachable by members.

These indicators do not by themselves prove misconduct. They indicate that the burden of proof should increase.

22.6. Illustration from local project communication

The experience of local projects such as `Soleil de Chanenc` shows why this clarification is necessary. A project may be presented as territorial, useful, or even citizen-oriented while leaving a decisive question unresolved: what direct and measurable benefit actually returns to residents?

A production site located in a valley is not yet a local benefit. A yearly educational action is not equivalent to a bill reduction. An investment opportunity is not identical to energy sharing. Territorial proximity is not proof of energy democracy.

This distinction is not intended to discredit projects. On the contrary, it aims to clarify the gaps between three levels that are often conflated:

- the presence of a renewable asset in a territory;
- the financial participation of residents;
- the effective organization of an energy community providing rights, savings, or shared governance.

22.7. Normative implication for OpenCEC

OpenCEC should encourage implementations to expose, for each public claim:

- the exact definition used;
- the corresponding protocol evidence;
- the participant-level economic consequence;
- the governance consequence;
- the verification method.

This can later support:

- a semantic compliance checklist;
- a labeling framework;
- anti-greenwashing audits;
- public-interest communication guidelines for PMOs and service operators.

In that sense, OpenCEC treats semantic rigor as part of protocol rigor. Ambiguous public language is not a merely cosmetic problem. It is often the first visible symptom of hidden asymmetry between narrative and reality.

23. Financial Drift and Anti-Financialization Principles

This chapter explains why OpenCEC must resist the substitution of physical energy assets by opaque financial products detached from real local machines, real local rights, and real local accountability.

23.1. Problem statement

A frequent drift consists in presenting as energy participation what is in reality a form of financial engineering. Instead of allowing citizens to invest in identifiable, measurable machines that are useful to a territory, some arrangements turn energy into a lead product, a speculative story, or an abstract asset.

In such a configuration, the citizen no longer finances a panel, a battery, an infrastructure, or a local flexibility capacity. They buy an opaque promise, often dependent on conditions they do not control, with fees, information asymmetries, windfall effects, and entry barriers.

23.2. Core principle

OpenCEC should prefer real energy assets over financialized representations of energy assets.

This means that the protocol and its governance should favor:

- physical traceability;
- measurable production or flexibility;
- explicit ownership or usage rights;
- transparent maintenance obligations;
- simple and auditable economic flows.

This preference should be read as structural rather than emotional. Financial instruments can be useful support tools. They become problematic when they replace the intelligible relationship between a participant, a machine, a measurable output, and a governed allocation rule.

23.3. Protocol capture risks

Beyond classic financialization, OpenCEC should explicitly recognize protocol-capture risks:

- proprietary extensions that silently fragment interoperability;
- closed algorithms that cannot be replayed or audited;
- dominant platforms that become de facto mandatory;
- artificial complexity that prevents informed contestation;
- dependency on one actor for data, hardware, or protocol interpretation.

These risks are central because capture can occur even when public language remains citizen-oriented.

23.4. Financial drifts to avoid

23.4.1. Speculation

When the logic of participation rests mainly on the expectation of resale, secondary valuation, or a return disconnected from real energy uses, the project moves away from the community purpose.

OpenCEC should not reward structures where value depends primarily on scarcity narratives, arbitrage opacity, or secondary market positioning.

In protocol terms, speculation is especially corrosive because it shifts attention away from operational truth. Instead of asking whether a community allocates energy fairly and coordinates flexibility intelligibly, the discussion drifts toward resale narratives, financial upside, and symbolic valuation detached from real system service.

23.4.2. Windfall effect

A windfall effect exists when actors capture most of the value created by a public or regulatory framework without building a genuine energy community.

Typical signs include:

- use of citizen language to unlock subsidies or public legitimacy;
- minimal redistribution of benefits to participants;
- concentration of control despite diffuse communication about participation;
- territorial communication without territorial return.

Another warning sign is the asymmetry between who assumes asset risk and who captures governance leverage. If citizens absorb reputational or financial risk while strategic control remains elsewhere, the arrangement is not approaching the OpenCEC ideal.

23.4.3. Excessive entry ticket

An energy community that requires too high an entry ticket reproduces the exclusions it claims to correct.

OpenCEC should encourage:

- progressive investment pathways;
- low-entry participation;
- modular ownership forms;
- access for households without large savings.

This point matters because a formally open project can remain socially closed if meaningful participation requires a capital threshold incompatible with ordinary households.

23.4.4. Opacity

Opacity is incompatible with any citizen-oriented claim. Particularly problematic are:

- legal structures that are difficult to understand;
- multiple remuneration layers;
- hidden fees;
- the absence of a readable link between asset, revenue, and risk;
- commercial messaging that is more detailed than governance documents.

23.4.5. Substitution of machines by paper claims

The critical point is this: the machine must not disappear behind the paper.

If a participant cannot answer, in plain terms:

- which asset exists,
- where it is,
- who operates it,
- how long it lasts,
- how maintenance is funded,
- and what exact right they have over it,

then the arrangement is drifting away from the OpenCEC philosophy.

An OpenCEC-compliant community should therefore be able to point to an `asset id`, an operator, an expected lifetime, a maintenance plan, and a measured contribution. Without this chain, the citizen-investment story remains under-specified.

23.5. OpenCEC position

OpenCEC does not reject finance. It rejects financial opacity and financial primacy.

Finance is acceptable when it remains subordinate to:

- a real machine;
- a real operating need;
- a real local community function;
- a real and intelligible risk allocation.

Finance becomes undesirable when it replaces the community-asset relationship with a packaged abstraction.

This is one of the reasons OpenCEC is cautious about models that accelerate capitalization faster than they clarify rights. Rapid financial scaling is not automatically evidence of democratic maturity. In some cases it may signal the opposite.

23.6. Normative consequences for the specification

The specification should later require that any citizen-facing investment scheme document:

- the physical asset financed;
- the expected technical output;
- the useful life and maintenance plan;
- the economic rights attached to participation;
- the exit conditions;
- the fee structure;
- the governance rights;
- the risk factors;
- the local allocation of benefits.

It should also require that this information remain available not only at subscription time, but throughout the useful life of the asset.

23.7. Democratic reason

Excessive financialization weakens energy democracy because it transfers real power to actors who master legal, accounting, and contractual language, to the detriment of ordinary participants.

A credible energy community should instead reduce asymmetries of understanding. It should make investment more concrete, more divisible, more progressive, and more verifiable.

In that sense, anti-financialization is not anti-economics. It is pro-legibility. It protects the chain that links energy reality, participant rights, and democratic control.

For the same reason, anti-capture is not anti-enterprise. A company `MAY` sell services. It `MUST NOT` own the common rules.

24. Evolutionary Perspective: Local Digital Currency and Energy-Backed Exchange

This chapter is exploratory. It does not define a mandatory feature of `OpenCEC 0.1`, and it should not be read as a requirement for `OpenCEC 1.0`.

Its purpose is to identify one possible long-term extension of the OpenCEC logic: the creation of a local digital currency or local digital unit of account using electricity as a first exchange good within a `CEC`.

24.1. Why this question emerges inside OpenCEC

OpenCEC treats electricity not only as a commodity, but as a measurable, allocable, and governable relation between local actors. Once local production, consumption, flexibility, and price signals become explicit, a further question naturally appears: can the community also create a local economic circuit organized around those measurable exchanges?

This question arises because electricity has several unusual properties in a `CEC` context:

- it is physically real;
- it is measured continuously;
- it is locally relevant;
- it is already linked to infrastructure investment;
- it is central to household budgets and local resilience.

For these reasons, electricity may become the first concrete exchange reference around which a local digital monetary layer could later be organized.

24.2. A possible long-term extension

In a future extension, a `CEC` could experiment with a local digital currency, local digital token, or local community unit of account linked to the real economic flows of the energy community.

The aim would not be speculative tokenization. The aim would be to create a local exchange instrument that remains tied to understandable physical and civic realities:

- electricity production;
- electricity savings;
- flexibility contribution;
- local investment effort;
- community service contribution.

In that perspective, electricity would serve as the first exchange good, not necessarily as the only one. Once a community accounting and trust layer exists, the same monetary circuit could potentially help value other local services or public-interest contributions.

24.3. Potential public-interest objectives

If designed carefully and lawfully, such a local monetary layer might pursue several public-interest goals:

- finance part of the local community infrastructure;
- support municipal or community services;
- encourage reinvestment in productive assets;
- retain value locally rather than exporting it immediately outside the territory;
- reduce dependence on distant financial intermediation;

- potentially relieve part of the fiscal pressure borne by local actors through better endogenous circulation of value.

This should be understood as a political-economic hypothesis, not as a present promise. The practical and legal conditions would be demanding.

24.4. Relation to monetary creation

One of the more ambitious variants of this idea is local monetary creation linked to productive community capacity.

In such a model, the community would not merely redistribute euros after the fact. It could create a controlled local monetary instrument against the expected value of real local energy production, flexibility, or shared infrastructure utility, within rules that remain public, auditable, and democratically governed.

The interest of this line of thought is that it reframes community energy as more than a bill-sharing mechanism. It becomes a possible base layer for a broader local economic commons.

24.5. Strict limits and anti-drift conditions

Because this topic is sensitive, OpenCEC should state strong safeguards from the outset.

Any future local digital currency layer should be:

- strictly secondary to the physical and operational electricity protocol;
- non-mandatory for OpenCEC compliance;
- transparent in issuance and redemption logic;
- non-speculative by design;
- governed by explicit local rules;
- auditable by participants;
- legally reviewed in each jurisdiction before deployment.

It should not become:

- a disguised financial product;
- a speculative token detached from community use;
- a mechanism for opaque leverage;
- a substitute for democratic governance;
- a pretext for recentralizing power in a technical operator.

24.6. Protocol implications

If such an extension were ever explored, OpenCEC could eventually provide protocol objects for:

- local units of account;
- issuance rules linked to community decisions;
- conversion or redemption events;
- traceable public-interest allocations;
- member wallets or ledgers under community governance;
- links between energy events and monetary events.

This does not belong to the core mandatory scope of `0.1`. It is better understood as a potential `Layer 5` extension above the current economic protocol.

24.7. Relationship with public services

The most interesting civic promise of this idea is not private enrichment. It is the possibility that a community-energy coordination layer could later help support public goods:

- maintenance of local infrastructures;
- social support mechanisms;
- local resilience funds;
- educational or technical services;
- municipal investments linked to the energy transition.

If local value creation becomes more visible and more governable, then part of that value may be redirected, by explicit democratic choice, toward services of collective interest.

24.8. Why this remains evolutionary

This chapter is intentionally framed as an evolutionary perspective.

OpenCEC `0.1` should first succeed at a more basic task:

- clarify energy coordination;
- make pricing auditable;
- enable local interoperability;
- support physical investment and democratic governance;
- resist greenwashing and financial capture.

Only after those foundations are stable would it make sense to evaluate whether a local digital monetary layer is desirable, lawful, and institutionally mature in a given territory.

For that reason, local digital currency should be discussed as a possible future extension of the OpenCEC ecosystem, not as a requirement of the standard and not as a condition for `OpenCEC 1.0`.

25. European Legal Corpus on ACC and CEC

This chapter identifies the main European legal texts relevant to collective self-consumption, renewable self-consumption, renewable energy communities, and citizen energy communities. It highlights the elements that matter most for OpenCEC.

25.1. Methodological note

This chapter does not reproduce the texts in full. It proposes a structured reading oriented toward the design of an open protocol. The important formulations are highlighted below, but they should later be connected to a complete legal citation apparatus, consolidated versions, and Member State transposition tables.

The legal method adopted here is selective and protocol-oriented. The question is not to summarize every clause of every directive. The question is to identify the legal hooks that justify an open coordination layer for allocation, price intelligibility, metering exchange, identity, and community governance.

25.2. Core legal corpus

25.2.1. Directive (EU) 2018/2001 on renewable energy, as amended

This is the central text for renewable self-consumption and renewable energy communities.

Structuring points for OpenCEC:

- **the directive explicitly frames renewable self-consumption of electricity** ;
- **it recognizes renewables self-consumers and jointly acting renewables self-consumers** ;
- **it allows renewable energy sharing within the same building, including collective buildings** ;
- **it requires Member States to provide an enabling framework for renewable self-consumption** ;
- **it recognizes renewable energy communities as legitimate actors of the energy system** ;
- **it requires an enabling framework for renewable energy communities** ;
- **it requires the removal of unjustified regulatory and administrative barriers** ;
- **it requires non-discriminatory treatment** ;
- **it emphasizes access for all consumers, including vulnerable households**.

OpenCEC reading:

- Article 21 is the legal root of collective renewable self-consumption.
- Article 22 is the legal root of renewable energy communities.
- The directive is not merely permissive; it expects Member States to actively enable these structures.

This distinction matters because many local implementations still behave as if community energy were tolerated only at the margins. The directive points in the opposite direction: enablement is part of the legal expectation.

25.2.2. Article 21: renewable self-consumers

For OpenCEC, the most important operational points are:

- **self-consumers may generate, consume, store and sell renewable electricity**;
- **joint self-consumption in the same building is expressly protected**;
- **sharing of renewable energy between such self-consumers is expressly permitted**;
- **Member States must create an enabling framework**;
- **that framework must address unjustified barriers to financing**;
- **that framework must address accessibility for low-income and vulnerable households**.

This matters because ACC should not be read as a narrow commercial exception. It is part of a wider European right to organize renewable self-consumption.

For OpenCEC, this means the protocol layer should not be architected as a workaround hidden inside supplier contracts. It should be designed as infrastructure for a recognized class of rights and practices.

25.2.3. Article 22: renewable energy communities

Most relevant points:

- **final customers are entitled to participate while maintaining their rights as customers**;
- **renewable energy communities may produce, consume, store and sell renewable energy**;
- **they may share renewable energy within the community**;
- **they may access suitable energy markets directly or through aggregation**;
- **DSOs must cooperate to facilitate energy transfers within the community**;
- **procedures and charges must be fair, proportionate and transparent**;
- **participation must be accessible, including for low-income and vulnerable households**;
- **tools facilitating access to finance and information must exist**.

For OpenCEC, this is particularly important: the European legal logic already points toward interoperability, non-discrimination, access to markets, and facilitation of internal transfers.

25.2.4. Directive (EU) 2019/944 on the internal market for electricity, as amended

This is the central text for citizen energy communities.

Structuring points:

- **Member States must provide an enabling regulatory framework for citizen energy communities** ;
- **participation must be open and voluntary** ;
- **members must be able to leave the community** ;
- **they do not lose their rights as final customers or active customers** ;
- **procedures, fees, and charges must be non-discriminatory, fair, proportionate, and transparent** ;
- **citizen energy communities may organize the sharing of electricity produced by the units they own** ;
- **they may, under certain conditions, own, establish, buy, lease, or manage distribution networks**.

OpenCEC reading:

- The CEC concept is broader than a pure renewable-production scheme.
- It belongs to the internal electricity market architecture, not only to renewable policy.
- It opens the door to more systemic forms of coordination than a narrow generation-sharing model.

This is one of the strongest legal arguments for separating community coordination from the supplier role. If CECs belong to the market architecture itself, they require explicit operational and informational tooling of their own.

25.2.5. Directive (EU) 2023/2413 (RED III)

This amending directive updates the renewable energy framework and raises the political and quantitative ambition of the Union.

Important points:

- **it strengthens the general framework for renewable deployment** ;

- **it confirms the structural place of communities and self-consumption in the transition** ;
- **it belongs to a logic of acceleration, not marginality**.

For OpenCEC, the key takeaway is that community-based renewable coordination is not a transitional exception but part of the mainstream policy direction.

25.2.6. Directive (EU) 2024/1711 on electricity market design reform

This text is especially important because it develops the legal framework for energy sharing.

Major points:

- **active customers are entitled to share renewable energy among themselves** ;
- **that sharing may rely on private agreements or on a legal entity** ;
- **an energy sharing organizer may be designated** ;
- **customers participating in sharing retain their consumer rights** ;
- **shared injected electricity may, under certain conditions, be deducted from measured consumption** ;
- **voluntary model contracts with fair and transparent conditions must be accessible** ;
- **vulnerable and energy-poor customers must be able to access energy sharing** ;
- **grid operators must provide the necessary information systems and contact points**.

This is a major development for OpenCEC because it pushes the legal framework closer to protocol questions:

- registration of sharing arrangements;
- metering data exchange;
- contractual templates;
- organizer roles;
- explicit treatment of vulnerable participants.

The emergence of an `energy sharing organizer` notion is particularly important. It shows that European law is getting closer to the exact interface layer OpenCEC wants to formalize: who coordinates, under which rules, with which information flows, and without collapsing the whole arrangement back into opaque supplier logic.

25.3. Interpretive consequences for OpenCEC

From these texts, several principles emerge:

- **European law is moving from tolerance to enablement**.
- **Energy communities are not supposed to remain exceptional pilot schemes**.
- **Internal sharing, self-consumption, and community coordination require transparent regulatory frameworks**.
- **Consumer rights remain central**.
- **Non-discrimination is not optional**.
- **Access for vulnerable households is explicitly part of the European logic**.
- **Data exchange, metering, and operational arrangements are increasingly recognized as necessary infrastructure**.

Another conclusion follows: compliance with European intent cannot be reduced to formal legal admissibility. A country may permit energy communities in theory while still lacking interoperable information systems, practical settlement tooling, or public algorithmic clarity.

25.4. Relevance for collective self-consumption in practice

For OpenCEC, ACC should therefore not be interpreted only as a French accounting allocation mechanism. It belongs to a broader European set that includes:

- renewable self-consumption;
- joint self-consumption;
- energy sharing;
- renewable energy communities;
- citizen energy communities.

This reading is essential because it supports the idea that a common protocol layer is still missing between legal categories and technical implementations.

The strategic implication is clear: OpenCEC should remain careful not to redefine the law, but ambitious in standardizing the technical and economic objects that the law increasingly presupposes.

26. French Grid Managers' View of CECs

This chapter summarizes, for the French case, how the two main grid-management levels tend to view collective self-consumption, energy communities, and related coordination needs.

The purpose is not to collapse OpenCEC into the perspective of incumbent network operators. It is to understand the constraints, enabling logic, and reservations that appear when CECs are seen from the distribution-system and transmission-system viewpoints.

26.1. Enedis: the distribution-system perspective

For Enedis, the most visible operational entry point is collective self-consumption. The emphasis is practical and procedural: a local project must be organized around metering points, a PMO, contractual interfaces, and implementation steps that can be processed reliably by the distribution-system operator.

From this perspective, a CEC is first encountered as:

- a legally organized local operation;
- a set of production and consumption points connected to the distribution grid;
- a data and settlement problem that requires clear rules;
- a deployment process that must be industrializable.

This viewpoint is coherent with Enedis documentation, which presents collective self-consumption as a local sharing arrangement and provides guides, implementation procedures, declaration forms, and model conventions with the PMO.

The Enedis view is therefore facilitative but structured. It is favorable to development insofar as:

- the project remains contractually and technically legible;
- the PMO role is explicit;
- metering and data exchange are operationally manageable;
- the operation can be integrated into existing information systems.

For OpenCEC, this means that a credible protocol layer should not ignore procedural realism. It should help PMOs and DSOs exchange auditable data with less friction, not produce a conceptually elegant but operationally unusable model.

26.2. RTE: the transmission-system perspective

For RTE, the primary lens is different. The issue is less the day-to-day processing of a local PMO file than the systemic effect of decentralized production and self-consumption on the national power system.

From this viewpoint, collective self-consumption and energy communities are part of a broader decentralization trend:

- more distributed generation;
- more local matching between production and consumption;
- new flexibility expectations;
- possible effects on peaks, balancing, and network financing.

RTE's published analyses recognize the development potential of self-consumption and local communities, but they also stress several system-level cautions:

- local self-consumption does not eliminate the need for networks;
- daytime PV matching does not solve winter evening peak problems by itself;
- strong development may require rethinking how network costs are financed;

- local coordination only creates system value when it effectively improves synchronization between local production and local consumption.

This is an important contribution to OpenCEC. It implies that a community protocol should not confuse local symbolic proximity with actual system benefit. The value of a local arrangement depends on when, where, and how it reduces stress on the wider system.

26.3. Productive tension between the two views

The Enedis and RTE perspectives are not contradictory. They operate at different levels.

- Enedis tends to see CECs through implementability on the distribution grid.
- RTE tends to see them through aggregate effects on the overall electricity system.

OpenCEC should be designed to speak to both.

At the distribution level, it must produce:

- clear metering semantics;
- reliable PMO interfaces;
- auditable allocation and settlement logic;
- operational compatibility with local implementation workflows.

At the system level, it must produce:

- interpretable price signals;
- visibility on balance contribution;
- visibility on network effects;
- room for flexibility and forecast quality.

This dual requirement is one reason the four-dimensional price model matters so much. A tariff that ignores balance, network, and forecast may be easy to communicate, but it loses contact with the concerns expressed at transmission-system level.

26.4. OpenCEC reading for France

For the French context, the lesson is not that CECs should be subordinated to network operators. The lesson is that a robust CEC protocol should remain intelligible to them.

If OpenCEC can provide:

- cleaner allocation traces for Enedis-facing operations;
- better visibility on local-versus-system effects for RTE-facing analysis;
- explicit service separation for PMOs;
- auditable participant-level consequences for communities,

then it can become a useful missing layer between legal possibility and operational scale.

Open question: later versions should compare the French DSO/TSO perspective with equivalent operator perspectives in other Member States, especially where local energy markets or energy-sharing frameworks are more mature.

27. Governance and Standardization Path

OpenCEC should evolve like an open technical standard, not like a closed product roadmap. Its legitimacy will depend on public review, reproducibility, and the visible possibility of disagreement and improvement.

27.1. Working Group logic

The most plausible institutional form is an OpenCEC Working Group with public documents, versioned drafts, issue tracking, and review cycles. Its role is not to centralize all community-energy decisions, but to maintain the specification and its testable invariants.

The expected versioning path is incremental:

- `0.1` for a first substantive specification;
- `0.2` for clarifications, benchmark additions, and protocol hardening;
- `1.0` for a stabilized release with stronger compliance tooling.

The working target should be to freeze `OpenCEC 1.0` in `2027`, following a public review cycle and a dedicated workshop in the `Ubaye Valley` in France, organized by `Soleil et Montagne` and `Aix-Marseille Universite`.

27.2. Public process

The governance process should resemble an RFC-like discipline:

- public issues;
- public review windows;
- written rationale for accepted changes;
- visible deprecation notices;
- archived discussions for major design choices.

27.3. Stakeholder roles

Relevant participants include:

- researchers;
- municipalities and local authorities;
- energy communities and PMOs;
- DSOs;
- regulators;
- civic and technical associations such as Hespul, négaWatt, REScoop, and Énergie Partagée;
- industrial implementers willing to accept vendor neutrality.

Electricity suppliers, including cooperative ones, may contribute to discussion, but caution is justified whenever their business logic remains supplier-centric rather than coordination-centric.

27.4. Parameter governance

Some parts of OpenCEC are not purely technical. Thresholds, convexity choices, default tolerances, and optional modules may require collective parameter setting. These decisions should be:

- explicit;
- versioned;
- contestable;
- justified in writing.

When a scalar collective choice is needed, the median vote has a strong default rationale, as discussed in the price-discovery chapter.

27.5. Constitutional boundary for participation

`One delivery point, one vote` is a technical default anchor, not a universal constitutional rule. A community constitution must distinguish the delivery point used for operational participation from the natural person, household, legal entity, or representative that holds a political right. It must publish eligibility, entry and exit, representation, delegation, multiple delivery points, tenant and owner roles, legal-person participation, quorum, abstention, conflicts of interest, emergency authority, appeal, and minority-protection rules.

No governance interface may infer a political right from a platform account. A SIGL credential proves an approved action under a policy; the dated community constitution determines whether that action-holder is eligible to vote or represent another person. A decision affecting allocation families, participant charges, asset rights, or personal data must identify its decision rule, notice period, evidence available to participants, effective date, and contestation procedure.

27.6. Confidential value voting for local decisions

OpenCEC should explicitly allow communities to use a `confidential value vote` when a local decision can be expressed as a scalar choice.

The default democratic intuition is simple:

- each eligible `delivery point` may submit one confidential value;
- the public result is the median of submitted values;
- the individual submitted value remains confidential.

This mechanism is relevant not only for energy parameters, but potentially for a much wider family of local choices whenever the community accepts the same governance channel.

Typical examples may include:

- numerical parameters for local flexibility or comfort policy;
- priority ranking converted into scalar scales;
- investment pacing preferences;
- local budget allocation between several numerically parameterized options;
- non-energy community choices expressed on a shared scale.

The attraction of this mechanism is that it remains both mathematically disciplined and politically legible. It avoids reducing every local choice to binary confrontation, while also avoiding the opacity of hidden weighting schemes.

Later versions of OpenCEC should therefore define:

- eligibility rules attached by default to the delivery point;
- confidentiality guarantees;
- opening and closing times for the vote;
- verifiable publication of the median result;
- archival and contestation procedures.

This should be understood as an enabling governance primitive of the protocol ecosystem, not as a requirement that every community must vote on every issue or must use the protocol for all forms of democracy.

The median is suitable only when the decision object is genuinely one-dimensional and the admitted values share a public scale. It must not be used to turn a qualitative choice, a constitutional amendment, or a conflict between incommensurable alternatives into a fictitiously scalar vote. For such decisions, the constitution must declare another intelligible procedure.

27.7. Near-term roadmap

After `0.1`, the most useful next steps are:

- publication of benchmark datasets and simulation tools;
- external review by researchers and practitioners;
- feedback from municipalities and associations;
- first compliance tests against reference implementations;
- refinement toward a more stable `1.0`;
- preparation of a `2027` workshop milestone intended to consolidate comments, country notes, and compliance principles before version freeze.

27.8. Research roadmap

OpenCEC should become a usable playground for:

- game theory;
- distributed optimization;
- mechanism design;
- multi-agent systems;
- forecasting;
- behavioral economics;
- grid simulation.

This orientation matters because the specification is not only a governance artifact. It is also intended to support universities, doctoral research, and European collaborative research projects.

27.9. European OpenCEC initiative

OpenCEC `0.1` is intended to bootstrap a broader standardization trajectory that may later include:

- an open specification;
- one or more reference implementations;
- a public algorithm arena;
- shared European datasets where lawful and feasible;
- a certification framework.

Potential long-term support environments include:

- Horizon Europe;
- LIFE Clean Energy Transition;
- Interreg cross-border projects.

This is not presented here as a funding request. It is a natural standardization roadmap for a European coordination layer.

27.10. Conformance language

The v2 language of philosophical, economic, and technical compliance is withdrawn because it could let an actor imply conformance without the corresponding enforceable profile. OpenCEC v3 instead uses the named profiles defined in `Document Status, Normative Convention, and Legal Boundary`. An organization may state that it supports OpenCEC values, but this is not a compliance claim and must not be presented as certification.

28. Public-Interest Theory of Change and Claim Discipline

This chapter is **INFORMATIVE**. It explains why a protocol for citizen energy communities can contribute to democratic resilience, ecological transition, economic legibility, and peaceful cooperation. It does not claim that a protocol alone guarantees any of those outcomes.

28.1. Theory of change

OpenCEC starts with public rules, interoperable evidence, scoped authorization, transparent allocation, explicit service remuneration, and participant control over data. These mechanisms can reduce information asymmetry and technical lock-in. Reduced asymmetry can make collective decisions, asset investment, consumer protection, local value retention, and cross-community cooperation easier to inspect and contest. When communities use those capacities fairly and within lawful grid coordination, they may improve energy resilience, distribute transition benefits more visibly, and reduce some sources of distrust and distributive conflict.

This is a contingent chain, not a physical law. It depends on inclusive governance, real access for households with limited resources, lawful market and grid integration, competent maintenance, fair parameter choices, and independent review. A community may implement the protocol and still fail socially or ecologically if it excludes people, conceals risk, transfers costs unfairly, or damages ecosystems.

28.2. Claim discipline

Any public claim that an OpenCEC implementation is `ecological`, `local`, `citizen`, `democratic`, `resilient`, or contributes to `peace` must identify: the mechanism; the geographic and temporal boundary; the counterfactual or baseline; the indicator; the data source; uncertainty; responsible party; and review date. A claim must distinguish measured result, modelled estimate, and political objective.

Allocation of a local kWh is not by itself evidence of lower greenhouse-gas emissions, lower network loss, reduced peak demand, biodiversity benefit, lower household cost, or social inclusion. These effects require separate evidence. The same rule applies to a claim of peace: OpenCEC may support cooperation, energy security, and fairer local value distribution, but it must not represent those contributions as proof that conflict has been prevented.

28.3. Minimum impact dashboard

Where an implementation makes public-interest claims, it should publish a versioned dashboard including: renewable production and its ownership boundary; allocated and unallocated volume; self-consumption and flexibility activation; peak and congestion indicators where available; household cost effects by declared category; participation and exit data; concentration of voting and asset rights; data-access and revocation statistics; lifecycle, land-use, maintenance, and biodiversity assumptions for new assets; and material exclusions or uncertainty.

The dashboard must not expose household-level energy behaviour. Aggregation thresholds, purpose limitation, retention, and disclosure review remain necessary.

28.4. Peaceful cooperation as a design constraint

The relevant contribution of OpenCEC is institutional rather than geopolitical. Open rules can make cross-community cooperation less dependent on opaque intermediaries; scoped credentials can allow a person to move between trusted communities without surrendering unrelated data; and auditable allocation can make the distribution of scarce local resources discussable rather than arbitrary. These are conditions that can support trust. They are not substitutes for democratic institutions, diplomacy, social protection, or climate policy.

29. Country-Specific National Contexts

This chapter is the country-specific layer of the specification. Its purpose is to gather, in one place for each Member State, the elements that are likely to vary nationally while keeping the core OpenCEC protocol as country-agnostic as possible.

The intended separation is the following:

- the core OpenCEC specification should remain reusable across countries;
- national sections should describe what changes from one legal and grid context to another;
- the protocol should be stable enough that country-specific constraints become explicit adaptation parameters rather than hidden redesigns.

29.1. Method

Each country note is written in English and follows the same structure:

- preliminary state of play for CECs, RECs, energy sharing, or collective self-consumption;
- transmission-system operator;
- distribution-system operator structure;
- preliminary operator vision for the future of CECs;
- OpenCEC opportunity;
- validation status.

Unless otherwise stated, the legal state of play is derived from the European Energy Communities Facility and related EU policy mappings. TSO names are aligned with ENTSO-E member information. Where an operator has not published an explicit position on CECs, the “operator vision” below is an inference from official role descriptions, self-consumption publications, grid-planning material, and public institutional mandates. These points are therefore explicitly `web-derived and pending confirmation`.

29.2. Austria

- Preliminary state of play: Austria is among the most advanced EU countries for energy-community transposition and practical implementation.
- TSO: Austrian Power Grid (`APG`).
- DSO structure: regional distribution operators; implementation is strongly distribution-level.
- Preliminary operator vision: favorable to energy communities when digital settlement, controllable local balancing, and grid-capacity management remain operationally tractable.
- OpenCEC opportunity: interoperability between advanced local implementation and a reusable public protocol layer.
- Validation status: `web-derived, pending confirmation by Austrian contributors and operators`.

29.3. Belgium

- Preliminary state of play: Belgium is legally active but structurally regionalized; the framework differs across Flanders, Wallonia, and Brussels.
- TSO: Elia.
- DSO structure: regional DSOs, notably Fluvius in Flanders, ORES/RESA and others in Wallonia, and Sibelga in Brussels.
- Preliminary operator vision: likely favorable to local energy communities when they can be integrated into region-specific metering, tariff, and market arrangements without undermining coordination across regions.

- OpenCEC opportunity: a protocol capable of spanning regional fragmentation while preserving common message and settlement semantics.
- Validation status: `web-derived, pending confirmation by Belgian regional contributors and DSOs`.

29.4. Bulgaria

- Preliminary state of play: the framework exists but the ecosystem remains early-stage and still needs enabling conditions for broad citizen deployment.
- TSO: Electricity System Operator (`ESO EAD`).
- DSO structure: distribution remains concentrated in a small number of licensed regional operators.
- Preliminary operator vision: emphasis is likely on transmission modernization, renewable integration, and operational reliability rather than on mature community-energy tooling.
- OpenCEC opportunity: create a transparent coordination layer early enough to avoid fragmented, ad hoc local implementations.
- Validation status: `web-derived, pending confirmation by Bulgarian contributors and operators`.

29.5. Croatia

- Preliminary state of play: the legal framework has evolved, but practical energy-sharing deployment remains weak and institutional support is still insufficient.
- TSO: HOPS.
- DSO structure: HEP-ODS is the main electricity distribution operator.
- Preliminary operator vision: likely cautious and implementation-centered, with concerns around information systems, metering roll-out, and the practical support of energy sharing.
- OpenCEC opportunity: provide public allocation and messaging logic where local implementation is currently slow or opaque.
- Validation status: `web-derived, pending confirmation by Croatian contributors and operators`.

29.6. Cyprus

- Preliminary state of play: the island context gives energy communities strategic relevance, but the market structure and operator organization remain highly centralized.
- TSO: Cyprus Transmission System Operator (`TSOC`).
- DSO structure: Electricity Authority of Cyprus, through its DSO unit, plays the central distribution role.
- Preliminary operator vision: likely favorable to local renewable participation if grid reliability, market control, and operational coordination remain tightly managed.
- OpenCEC opportunity: define auditable local sharing and flexibility objects in a system where central coordination remains strong.
- Validation status: `web-derived, pending confirmation by Cypriot contributors and operators`.

29.7. Czech Republic

- Preliminary state of play: the Czech framework is moving forward, with an emerging coalition around community energy and growing implementation interest.
- TSO: ČEPS.
- DSO structure: the main DSOs are ČEZ Distribuce, EG.D, and PREdistribuce.
- Preliminary operator vision: likely pragmatic, focused on secure data exchange, territory-based distribution management, and the orderly integration of decentralized resources.
- OpenCEC opportunity: help standardize allocation and settlement across a multi-DSO environment.

- Validation status: `web-derived, pending confirmation by Czech contributors and operators`.

29.8. Denmark

- Preliminary state of play: Denmark has strong cooperative and wind-community traditions, but not all historical cooperative models are identical to current EU energy-community categories.
- TSO: Energinet.
- DSO structure: multiple DSOs operate at regional level.
- Preliminary operator vision: likely favorable to decentralized participation provided that system efficiency, market coordination, and balancing responsibilities remain explicit.
- OpenCEC opportunity: connect strong cooperative culture with a more formal protocol treatment of energy sharing and democratic price discovery.
- Validation status: `web-derived, pending confirmation by Danish contributors and operators`.

29.9. Estonia

- Preliminary state of play: Estonia has an emerging policy and practice landscape, with visible interest in community models but still limited scale.
- TSO: Elering.
- DSO structure: many DSOs exist, but Elektrilevi is dominant by market share.
- Preliminary operator vision: likely shaped by security-of-supply, balancing, and digital-system priorities, with interest in efficient integration of distributed resources.
- OpenCEC opportunity: leverage Estonia's digital orientation for auditable protocol-native community coordination.
- Validation status: `web-derived, pending confirmation by Estonian contributors and operators`.

29.10. Finland

- Preliminary state of play: Finland has many DSOs and a mature regulatory environment, but the community-energy framework remains less symbolically central than in some other Member States.
- TSO: Fingrid.
- DSO structure: dozens of DSOs; large operators include Caruna, Elenia, and Helen's distribution-related entities.
- Preliminary operator vision: likely focused on regulated network efficiency, reliability, and distributed integration rather than on politically prominent community branding.
- OpenCEC opportunity: make local sharing and flexibility coordination legible in a technically mature but institutionally fragmented distribution landscape.
- Validation status: `web-derived, pending confirmation by Finnish contributors and operators`.

29.11. France

- Preliminary state of play: France has a functioning but still fragmented framework built around collective self-consumption, PMOs, and gradually evolving territorial experiments.
- TSO: RTE.
- DSO structure: Enedis covers most of the territory, alongside local distribution companies (`ELDs`).
- Preliminary operator vision: Enedis tends to approach CEC-adjacent development through implementable collective self-consumption procedures and data flows; RTE tends to assess local coordination through system-level effects on balancing, peaks, and network financing.
- OpenCEC opportunity: bridge ACC practice, PMO operations, explicit price logic, and auditable local-versus-system effects.
- Validation status: `web-derived, pending confirmation by French contributors and operators`.

29.12. Germany

- Preliminary state of play: Germany combines a strong cooperative legacy with a highly fragmented DSO landscape and a mature but complex grid environment.
- TSO: Amprion, 50Hertz, TenneT Germany, and TransnetBW.
- DSO structure: more than 800 DSOs operate in Germany.
- Preliminary operator vision: likely favorable to decentralized participation in principle, but strongly conditioned by congestion management, digitalization, and local network-planning constraints.
- OpenCEC opportunity: make interoperability and replaceability possible in a highly fragmented operator and municipal environment.
- Validation status: `web-derived, pending confirmation by German contributors and operators`.

29.13. Greece

- Preliminary state of play: Greece has a visible energy-community discourse and a legal basis, but practical implementation remains uneven.
- TSO: IPTO (`ADMIE`).
- DSO structure: Hellenic Electricity Distribution Network Operator (`HEDNO/DEDDIE`).
- Preliminary operator vision: likely supportive where communities help renewable integration and local resilience, but cautious where information systems, queues, or network stress become limiting.
- OpenCEC opportunity: clarify community rights and algorithmic transparency in a context where formal recognition is ahead of uniform operational maturity.
- Validation status: `web-derived, pending confirmation by Greek contributors and operators`.

29.14. Hungary

- Preliminary state of play: Hungary remains an emerging case, with coalition-building around community energy but limited large-scale operational deployment.
- TSO: MAVIR.
- DSO structure: several regional DSOs operate under a regulated national framework.
- Preliminary operator vision: likely centered on orderly grid management, regulated access, and gradual accommodation of distributed actors rather than rapid community-market experimentation.
- OpenCEC opportunity: introduce a public coordination grammar before closed proprietary local models become dominant.
- Validation status: `web-derived, pending confirmation by Hungarian contributors and operators`.

29.15. Ireland

- Preliminary state of play: Ireland shows growing policy and community interest, but scaling and practical accessibility remain work in progress.
- TSO: EirGrid.
- DSO structure: ESB Networks is the central distribution operator.
- Preliminary operator vision: likely supportive where community participation aligns with decarbonization, flexibility, and planned network evolution.
- OpenCEC opportunity: couple strong public-transition language with auditable local allocation and participant-level economic visibility.
- Validation status: `web-derived, pending confirmation by Irish contributors and operators`.

29.16. Italy

- Preliminary state of play: Italy has moved rapidly on renewable energy communities and collective self-consumption, with a strong policy and cooperative dynamic.
- TSO: Terna.

- DSO structure: e-distribuzione is dominant, alongside other DSOs including Areti and Unareti in specific territories.
- Preliminary operator vision: likely favorable to scaling distributed participation, provided tariff treatment, data exchange, and settlement remain administratively robust.
- OpenCEC opportunity: turn rapid community growth into interoperable public protocol practices rather than heterogeneous local silos.
- Validation status: `web-derived, pending confirmation by Italian contributors and operators`.

29.17. Latvia

- Preliminary state of play: Latvia is still at an early stage, though policy and rural-community actors are increasingly engaged.
- TSO: Augstsprieguma tīkls (`AST`).
- DSO structure: distribution is strongly centered on Sadales tīkls.
- Preliminary operator vision: likely focused on secure integration of distributed production and modernization rather than fully developed community-market tooling.
- OpenCEC opportunity: define community coordination logic early in a still-maturing ecosystem.
- Validation status: `web-derived, pending confirmation by Latvian contributors and operators`.

29.18. Lithuania

- Preliminary state of play: Lithuania has been active on prosumer and local-energy issues, but the citizen/community layer remains institutionally uneven.
- TSO: Litgrid.
- DSO structure: distribution is strongly centered on ESO Lithuania.
- Preliminary operator vision: likely favorable to digital and distributed integration while remaining attentive to network stability and data-governance issues.
- OpenCEC opportunity: align existing digital-energy capability with more explicit community protocol objects.
- Validation status: `web-derived, pending confirmation by Lithuanian contributors and operators`.

29.19. Luxembourg

- Preliminary state of play: Luxembourg has visible cooperative energy actors and a manageable national scale, but a limited ecosystem size.
- TSO: Creos Luxembourg.
- DSO structure: Creos also plays the major distribution role.
- Preliminary operator vision: likely favorable to structured local-energy experimentation if the operational burden remains proportionate and system visibility remains high.
- OpenCEC opportunity: a compact national testbed for interoperable CEC protocol design.
- Validation status: `web-derived, pending confirmation by Luxembourg contributors and operators`.

29.20. Malta

- Preliminary state of play: Malta's island system makes local generation and community coordination strategically interesting, but the system remains structurally centralized.
- TSO: Malta operates as a small-island electricity system without the same mainland multi-operator pattern; Enemalta is the key system actor.
- DSO structure: Enemalta is also the main distribution actor.

- Preliminary operator vision: likely cautious, reliability-first, and sensitive to system-scale constraints, but potentially open to community models that improve local renewable uptake.
- OpenCEC opportunity: formalize a community layer in a tightly bounded and operationally legible system.
- Validation status: `web-derived, pending confirmation by Maltese contributors and operators`.

29.21. Netherlands

- Preliminary state of play: the Netherlands has one of the most mature organized community-energy ecosystems in Europe.
- TSO: TenneT Netherlands.
- DSO structure: major DSOs include Liander, Enexis, and Stedin.
- Preliminary operator vision: increasingly shaped by congestion management, local flexibility, and digital coordination of distributed resources.
- OpenCEC opportunity: protocolize already active community practice while addressing congestion, data portability, and federation.
- Validation status: `web-derived, pending confirmation by Dutch contributors and operators`.

29.22. Poland

- Preliminary state of play: Poland is still emerging in the community-energy domain, though energy cooperatives and related coalitions are growing.
- TSO: PSE.
- DSO structure: major DSOs are linked to the large utility groups, including PGE Dystrybucja, Tauron Dystrybucja, Energa-Operator, Enea Operator, and Stoen Operator.
- Preliminary operator vision: likely cautious and grid-capacity oriented, with community-energy growth conditioned by broader power-system transition and market reform.
- OpenCEC opportunity: avoid path dependence toward opaque, utility-shaped local models by introducing open coordination semantics early.
- Validation status: `web-derived, pending confirmation by Polish contributors and operators`.

29.23. Portugal

- Preliminary state of play: Portugal has an active cooperative nucleus and visible legal movement on renewable self-consumption and communities.
- TSO: REN.
- DSO structure: E-Redes is the principal electricity distribution operator.
- Preliminary operator vision: likely favorable where distributed coordination supports renewable deployment and manageable network evolution.
- OpenCEC opportunity: connect cooperative innovation with explicit protocol logic for allocation, pricing, and participant rights.
- Validation status: `web-derived, pending confirmation by Portuguese contributors and operators`.

29.24. Romania

- Preliminary state of play: Romania remains an early but promising case, with visible first movers and coalition-building.
- TSO: Transelectrica.
- DSO structure: several regional DSOs operate, including operators linked historically to Electrica, Delgaz Grid, and Distribuție Energie Electrică Romania.
- Preliminary operator vision: likely focused on orderly renewable integration, investment needs, and incremental digital modernization.

- OpenCEC opportunity: create a shared protocol layer before the ecosystem fragments into incompatible local arrangements.
- Validation status: `web-derived, pending confirmation by Romanian contributors and operators`.

29.25. Slovakia

- Preliminary state of play: Slovakia has an evolving but still modest community-energy environment.
- TSO: SEPS.
- DSO structure: distribution is carried by the regional DSOs ZSD, SSD, and VSD.
- Preliminary operator vision: likely conservative and grid-security oriented, with gradual interest in distributed and local coordination tools.
- OpenCEC opportunity: make future community deployment more interoperable from the outset.
- Validation status: `web-derived, pending confirmation by Slovak contributors and operators`.

29.26. Slovenia

- Preliminary state of play: Slovenia has an active policy and civil-society conversation around energy communities, with growing practical interest.
- TSO: ELES.
- DSO structure: distribution is organized through regional operators under a national framework.
- Preliminary operator vision: likely favorable to local renewable coordination where measurement, balancing, and network impacts remain transparent.
- OpenCEC opportunity: provide a clear open standard for a relatively agile national ecosystem.
- Validation status: `web-derived, pending confirmation by Slovenian contributors and operators`.

29.27. Spain

- Preliminary state of play: Spain combines strong cooperative actors, significant renewable growth, and increasing relevance of local energy-sharing arrangements.
- TSO: Red Eléctrica (REE).
- DSO structure: major DSOs include e-distribución, i-DE, UFD, E-Redes Distribución Eléctrica, and Viesgo/other regional operators.
- Preliminary operator vision: increasingly attentive to distributed renewables, local flexibility, and grid hosting capacity, while remaining sensitive to congestion and system cost allocation.
- OpenCEC opportunity: connect strong cooperative practice with a public and interoperable protocol layer.
- Validation status: `web-derived, pending confirmation by Spanish contributors and operators`.

29.28. Sweden

- Preliminary state of play: Sweden has relevant local-energy and cooperative traditions, but the energy-community framework is less institutionally central than in some southern Member States.
- TSO: Svenska kraftnät.
- DSO structure: large DSOs include Ellevio, E.ON Energidistribution, and Vattenfall Eldistribution alongside smaller operators.
- Preliminary operator vision: likely focused on network investment, reliability, and electrification rather than on community branding as such.
- OpenCEC opportunity: express community coordination in a way that speaks to electrification, flexibility, and transparent local system value.
- Validation status: `web-derived, pending confirmation by Swedish contributors and operators`.

29.29. Cross-Country Reading

Across the Union, one common pattern emerges: legal recognition of communities is spreading faster than interoperable technical and economic implementation. In many countries, DSOs are the practical bottleneck because metering, data exchange, and local settlement all touch the distribution grid. TSOs, by contrast, tend to evaluate community development through system-level concerns such as balancing, financing, congestion, and adequacy.

This asymmetry reinforces the OpenCEC design choice. The protocol should stay general enough to apply across countries, but explicit enough that national operator constraints become visible adaptation inputs rather than hidden and unstructured exceptions.

30. Conclusion

30.1. Open specification and historical analogy

OpenCEC is intended as an open specification, not as a closed product architecture. Its vocation is closer to that of Internet standards than to that of a vertically integrated platform. The point is not to centralize all implementations, but to make heterogeneous implementations interoperable under shared public rules.

This analogy matters because the decisive contribution of Internet protocols was not to own infrastructures or services. It was to define a common layer through which diverse actors could communicate, coordinate, innovate, and compete without prior institutional uniformity. OpenCEC seeks a similar role for Citizen Energy Communities.

30.2. Electricity economics as a protocol matter

One of the central claims of this document is that the economics of electricity communities should not remain hidden inside opaque contractual stacks. Allocation, price discovery, flexibility, local balancing, and network-sensitive coordination can be treated as explicit protocol objects rather than as proprietary commercial black boxes.

In that sense, OpenCEC does not ignore the economics of electricity. It takes them seriously enough to make them discussable, auditable, and governable.

This is also what most clearly distinguishes a CEC from a conventional electricity supplier. The supplier primarily commercializes electricity. The CEC, in the OpenCEC sense, organizes cooperation around electricity.

30.3. Democratic power of Citizen Energy Communities

At their best, Citizen Energy Communities are not merely a tool for marginal local participation. They create a concrete democratic capacity in the energy system: the capacity to co-own assets, to understand rules, to influence allocation, to shape local investment, and to retain part of the value created by energy infrastructures within the communities that live with them.

This democratic power is real only if it reaches beyond symbolic participation. It must be visible in rights, in bills, in access conditions, in investment pathways, and in the ability to contest or change collective rules.

30.4. Vigilance against capture

For that reason, vigilance is necessary. The emergence of an open and citizen-oriented layer in the electricity system may be slowed, reshaped, or neutralized by several forms of pressure:

- capture by large incumbent actors;
- dilution through lobbying;
- replacement of civic language by financial engineering;
- public-policy hesitation or over-conditioning;
- administrative complexity that exhausts local initiatives before they mature.

The risk is not only open opposition. It is also domestication: retaining the vocabulary of communities, sharing, and democracy while removing their operational substance.

OpenCEC should therefore remain attentive to all mechanisms through which financial power, industrial concentration, lobbying influence, or political caution can re-close a field that European law has begun to open.

30.5. Guiding principle

OpenCEC does not define who owns energy. OpenCEC defines how autonomous energy actors cooperate.

That is why the specification should remain open, inspectable, replaceable, and difficult to capture. Its success will not be measured only by technical adoption. It will be measured by whether communities can actually use it to make energy rights more legible, prices more democratic, services more explicit, and local value less vulnerable to rhetorical or financial capture.

31. Annexes

31.1. Annex A: Water Filling Proof Sketch

Let residual demands be $c_1, \ldots, c_n \geq 0$ and total residual production be $P \geq 0$. The water-filling allocation problem seeks a vector $a_1, \ldots, a_n$ such that:

- $0 \leq a_i \leq c_i$ for all i;
- $\sum_i a_i = \min\left(P, \sum_i c_i\right)$;
- the remaining unsatisfied demand vector is equalized as far as possible.

The iterative construction used in the main text progressively distributes equal layers of energy to all still-unsatisfied participants. The proof sketch is straightforward.

1. `Feasibility`: every iteration adds a non-negative common increment to active participants and stops before any participant exceeds its residual demand. Therefore $a_i \leq c_i$ always holds.
2. `Resource exhaustion`: if eligible residual demand exists in the level being processed, every iteration subtracts exactly `delta * |active|` from remaining production. Hence that level either exhausts its available energy or satisfies every eligible residual demand.
3. `Symmetry`: participants with identical residual demand remain identical under every iteration because they receive the same increments and exit the active set at the same threshold.
4. `Anonymity`: the rule depends only on the residual demand vector, not on participant labels.
5. `No arbitrary priority`: unlike queue-based rules, no participant obtains preference from ordering alone.

This does not prove that water filling is universally optimal for every conceivable fairness notion. It proves that it satisfies a coherent family of properties particularly aligned with CLAIRE: equal treatment of comparable situations, no hidden bilateral favoritism after level `0`, and full use of energy available to a level when eligible demand exists.

31.2. Annex B: MQTT Profile for OpenCEC

This annex summarizes the MQTT-oriented profile used by `OpenCEC 0.1`.

It should be read as an implementation profile for the current draft, not as the final transport horizon of OpenCEC. Later versions may keep MQTT compatibility while introducing a more native protocol profile such as `Alpha`.

31.3. Namespace

All normative topics should begin with `opencec/v0.1/`.

31.4. Recommended topic families

- `opencec/v0.1/{cec_id}/meter/{dp_id}/measurement`
- `opencec/v0.1/{cec_id}/forecast/{actor_id}`
- `opencec/v0.1/{cec_id}/allocation/{period}`
- `opencec/v0.1/{cec_id}/price/{period}`
- `opencec/v0.1/{cec_id}/flexibility/{asset_id}`

31.5. QoS profile

- Measurements: QoS 1 recommended.
- Allocation and price outputs: QoS 1 with retained state where relevant.
- Discovery topics: retained messages recommended.

31.6. Minimal security expectations

- authenticated client connection;

- signed or integrity-protected payloads at application level where required;
- replay-window checks based on `message_id` and `timestamp`.

31.7. Versioning

Breaking changes should change the version segment of the topic path. Implementations should reject unknown major versions rather than silently reinterpret payloads.

31.8. Annex C: Simulation Framework

The simulation framework should allow researchers and implementers to compare allocation, pricing, forecasting, and flexibility algorithms under shared assumptions.

31.9. Minimum inputs

- time-series production data;
- time-series consumption data;
- actor identity groupings;
- optional forecast data;
- optional network-distance or locality indicators;
- optional flexibility assets and constraints.

31.10. Benchmark families

- surplus-rich sunny periods;
- scarcity periods;
- highly unequal demand distributions;
- forecast error stress cases;
- temporary communication failure scenarios.

31.11. Reproducibility rule

Every published benchmark result should disclose:

- code version;
- scenario identifier;
- input dataset version;
- algorithm version;
- output metrics.

31.12. Annex D: Glossary

- `CEC`: Citizen Energy Community.
- `REC`: Renewable Energy Community.
- `PMO`: organizing legal entity operating or coordinating part of the community stack.
- `DP`: delivery point identifier used for metering and settlement boundaries.
- `Delivery point`: the metering and settlement boundary used as the default physical participation anchor for many OpenCEC rights and obligations. In French national contexts, this often corresponds to the term `PDL` (`Point de Livraison`).
- `ACI`: individual self-consumption.
- `Remote AC`: multi-site or remote individual self-consumption by the same actor across several metering points.
- `ACC`: collective self-consumption arrangement, especially in the French context.
- `Alpha`: provisional name for a future OpenCEC-native transport profile based on register/publish/subscribe logic, compact binary payloads, and integrated time-series history access.
- `BRP`: balance responsible party, or equivalent entity carrying balancing responsibility in a market perimeter.

- `Energy Edge Gateway`: generic term for a participant-side device connecting the electrical panel, local assets, local control logic, and the OpenCEC communication layer.
- `Community Energy Node`: generic term for a community-side server responsible for shared coordination, history, algorithms, and external interfaces.
- `Demand response / effacement`: deliberate load reduction, shifting, or modulation in response to system or market signals.
- `Volume allocation`: protocol operation that attributes kWh shares independently from valuation.
- `Price discovery`: protocol operation that derives a public and auditable price from explicit components.
- `Flexibility`: ability to shift, modulate, store, or release energy in response to protocol signals.
- `Energy identity`: durable identifier linking protocol objects to a participant, asset, meter, or community role.
- `SIGL`: OpenCEC passwordless authorization profile based on hardware-backed mobile keys, action-bound cryptographic challenges, and auditable approval receipts.
- `SIGL credential`: the scoped association between a non-secret public-key reference and an OpenCEC role, mandate, asset, delivery point, charge point, or federation agreement.
- `SIGL decision receipt`: auditable record connecting a consequential OpenCEC action to its challenge, public-key reference, policy, approval time, delegation if any, and resulting protocol object.
- `Roaming-charge`: SIGL capability authorizing a holder to start an EV charge session in a host ACC or CEC under a defined roaming and settlement agreement.
- `SIGL data-access grant`: scoped, purpose-bound, time-bounded, and revocable authorization for a participant or delegate to read, export, or receive a defined OpenCEC data category.
- `Electrical distance`: proxy for infrastructural locality or relative network burden between points.
- `Collectivisable energy`: for one settlement interval, the minimum of total active production and total active consumer demand; it is the maximum volume that can be allocated collectively.
- `CLAIRE-1.0`: OpenCEC normative volume-allocation profile: level-0 self-consumption by legal entity, complete mutualisation of residual production, then strict priority-family water filling.
- `Priority family`: dated and ordered governance-defined set of consumer delivery points eligible to receive collective residual production after level 0.
- `DP-WF-0.1`: delivery-point water-filling transport baseline. It does not implement CLAIRE-1.0 without the legal-entity level and ordered priority families.
- `Allocation key`: rounded percentage transport representation of an already calculated Wh allocation; it is not the allocation rule itself.
- `Dated perimeter`: versioned register of delivery points, roles, and effective participation dates used to determine the active set for every interval.

31.13. Annex E: Compliance Summary Table

This annex provides a compact working summary of the principles that any OpenCEC-compliant implementation should respect in full.

Requirement	Level	Test method	Section
No hidden kWh margin	Core mandatory	accounting audit	Foundational Principles
Public algorithm	Core mandatory	source and documentation review	Principles; Allocation; Arena
Price vector visible	Core mandatory	message inspection	Price Discovery; Protocol

Data export	Core mandatory	interoperability test	Interoperability; Reference Implementation
Vendor replaceability	Core mandatory	migration test	Reference Implementation
CLAIRE level-0 self-consumption by legal entity	CLAIRE-1.0	allocation trace review	Volume Allocation
Residual mutualisation and ordered priority families	CLAIRE-1.0	allocation replay test	Volume Allocation
CLAIRE water-filling rule	CLAIRE-1.0	official and randomized conformance tests	Volume Allocation
Dated perimeter and active-set enforcement	CLAIRE-1.0	mid-period enrolment and departure test	Volume Allocation; Annex H
Wh conservation and demand-cap adherence	CLAIRE-1.0	full-period allocation replay	Volume Allocation; Annex H
Complete active-PRM key vector	National adapter	adapter conformance test	Volume Allocation; Annex H
Versioned correction and preserved prior allocation	CLAIRE-1.0	meter-correction replay test	Volume Allocation
Four-component price explainability	Core mandatory	pricing audit	Price Discovery
Protocol version visibility	MQTT-Transport-0.1	message inspection	Protocol Layer
SIGL verification in management tools	SIGL-Authorization-0.1	cross-tool authorization test	SIGL Profile
Scoped authorization and decision receipt	SIGL-Authorization-0.1	challenge, revocation, and audit test	SIGL Profile
ACC roaming-charge interoperability	Mobility experimental	home/host charge-session test	SIGL; Interoperability
Replay protection	MQTT-Transport-0.1	security test	Protocol Layer
Real citizen asset linkage	Core mandatory	asset and governance review	Financial Drift
Explicit service fee	Core mandatory	billing review	Reference Implementation

An actor may claim only the precisely named profiles for which every mandatory requirement is satisfied. It must not use the unqualified claim `OpenCEC compliant` unless it satisfies `OpenCEC Core` and declares all additional profiles, versions, test results, and deviations. Alignment with the values of OpenCEC is not conformance.

31.14. Annex F: Selected Bibliography

This bibliography is intentionally selective. It includes only real and verified references used to structure the present draft. It is organized by thematic use inside the specification.

31.14.1. Law and Regulation

- Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast). EUR-Lex.
- Directive (EU) 2019/944 of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity. EUR-Lex.
- Directive (EU) 2023/2413 of the European Parliament and of the Council of 18 October 2023 amending Directive (EU) 2018/2001, Regulation (EU) 2018/1999 and Directive 98/70/EC as regards the promotion of energy from renewable sources. EUR-Lex.
- Directive (EU) 2024/1711 of the European Parliament and of the Council of 13 June 2024 amending Directives (EU) 2018/2001 and (EU) 2019/944 as regards improving the Union’s electricity market design. EUR-Lex.
- CRE. `Transition énergétique dans les territoires : nouvelles villes, nouveaux réseaux, nouveaux services`, Rapport du groupe de travail no. 2, 2019. https://www.cre.fr/fileadmin/Documents/Rapports_et_etudes/import/Rapport-GT2.pdf
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31.14.2. Institutional and Policy Mapping

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- European Energy Communities Facility. `National policy frameworks for energy communities`. https://energycommunitiesfacility.eu/resources/national-policy-frameworks
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31.14.3. Grid Operators and System Design

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- Enedis. `Tout savoir sur l'autoconsommation collective`. https://www.enedis.fr/tout-savoir-sur-lautoconsommation-collective
- Enedis. `Autoconsommation collective — Guide pédagogique`, 2024. https://www.enedis.fr/sites/default/files/documents/pdf/autoconsommation-collective-guide-pedagogique.pdf

- RTE. `Électricité : l'autoconsommation, un remède à la crise de l'énergie ?` https://www.rte-france.com/bases-electricite/consommation-electricite/electricite-autoconsommation-remede-crise-energie
- RTE. `Schéma décennal de développement du réseau 2019, Chapitre 11 : L'autoconsommation et les modalités de développement du solaire`, 2020. https://assets.rte-france.com/prod/public/2020-07/SDDR%202019%20Chapitre%2011%20-%20L%27autoconsommation%20et%20les%20modalit%C3%A9s%20de%20d%C3%A9veloppement%20du%20solaire.pdf

31.14.4. Community Energy, Governance, and Social Design

- Lowitzsch, J., Hoicka, C. E., van Tulder, F. J. `Renewable and citizen energy communities in the European Union`. Journal of Sustainable Development of Energy, Water and Environment Systems, 8(3), 2020. DOI: [10.13044/j.sdewes.d7.0325](https://doi.org/10.13044/j.sdewes.d7.0325)
- Ahmed, S., Ali, A., D'Angola, A. `A Review of Renewable Energy Communities: Concepts, Scope, Progress, Challenges, and Recommendations`. Sustainability, Volume 16, Issue 5, 2024, Article 1749. DOI: [10.3390/su16051749](https://doi.org/10.3390/su16051749)
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- Moroni, S., Alberti, V., Antoniucci, V., Bisello, A. `How national policies influence energy community development? A review of REC models in EU countries`. Utilities Policy, Volume 90, 2024, Article 101792. DOI: [10.1016/j.jup.2024.101792](https://doi.org/10.1016/j.jup.2024.101792)

31.14.5. Pricing, Allocation, and Algorithms

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- Soto, E. A., Bosman, L. B., Wollega, E., Leon-Salas, W. D. `Peer-to-peer energy trading: A review of the literature`. Applied Energy, Volume 283, 2021, Article 116268. DOI: [10.1016/j.apenergy.2020.116268](https://doi.org/10.1016/j.apenergy.2020.116268)

31.14.6. Theses and dissertations

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- Shilov, N. `Game-Theoretic Approaches for Peer-to-Peer Energy Trading`. Doctoral thesis, Institut Polytechnique de Paris, 2023. HAL thesis record: [tel-04371365](https://theses.hal.science/tel-04371365)

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- `Méthodes d'optimisation pour les communautés d'énergie locales`. Doctoral thesis, Université Grenoble Alpes, 2023. Thèses.fr identifier: [2023GRALT083](https://theses.fr/2023GRALT083)

31.15. Annex G: Contribution and Review Plan

This annex lists the organizations that should be solicited for contribution, correction, review, or challenge. It is a working outreach map, not a formal governance body.

The logic of this list is to combine:

- citizen-energy practitioners;
- European support structures;
- grid operators and regulators;
- implementation actors;
- leading research groups relevant to allocation, pricing, interoperability, local markets, and community-energy governance.

31.16. European-level organizations

- European Commission, DG Energy.
- European Energy Communities Facility.
- Energy Communities Repository legacy network and national experts.
- REScoop.eu.
- FEDARENE.
- Energy Cities.
- CEMR, where local-authority feedback is useful.
- CEER, for regulatory dialogue where relevant.
- ACER, for high-level regulatory consistency questions.
- DSO Entity.
- ENTSO-E.

31.17. France

- Soleil et Montagne.
- Énergie Partagée.
- Hespul.
- négaWatt.
- Enedis.
- RTE.
- CRE.
- Local distribution companies (`ELDs`) where relevant.

31.18. National community-energy interlocutors by country

- Austria: OurPower, Koordinationsstelle Energiegemeinschaften.
- Belgium: REScoop Vlaanderen, REScoop Wallonie, Energie Samen-type regional interlocutors where relevant.
- Bulgaria: izgrei BG, Green Synergy Cluster.
- Croatia: ZEZ, Community Energy Coalition in Croatia.
- Cyprus: Cyprus Energy Agency.
- Czech Republic: UKEN, ENERKOM Podlipansko.
- Denmark: Energifællesskaber Danmark, Middelgrunden cooperative.

- Estonia: Energiaühistu, Tartu Regional Energy Agency.
- Finland: Green Net Finland.
- Germany: Netzwerk Energiewende Jetzt, Bündnis Bürgerenergie, Bürgerwerke.
- Greece: DESMI, Electra Energy.
- Hungary: Solidarity Economy Center, Friends of the Earth Hungary.
- Ireland: Community Energy Federation of Ireland, Community Power.
- Italy: ènostra, Retenergie, Confcooperative Consumo e Utenza.
- Latvia: Latvian Rural Forum, Green Liberty.
- Lithuania: LVBOS, Lithuanian local community organizations.
- Luxembourg: Energy Revolt, CELL.
- Malta: Malta Cooperative Federation.
- Netherlands: Energie Samen, Econobis-oriented ecosystem actors.
- Poland: SERC Alliance, ZAE-linked cooperative actors.
- Portugal: Coopérnico.
- Romania: Cooperativa de Energie.
- Slovakia: SAPI.
- Slovenia: Focus, Network for Energy Communities.
- Spain: Som Energia, Unión Renovables, Goiener.
- Sweden: SERO, Sveriges Energigemenskaper.

31.19. Grid operators and institutional reviewers

The country fiches should also be submitted, where possible, to relevant transmission and distribution operators for factual correction.

- Transmission operators should be approached through the national TSO identified in the country chapter.
- Distribution operators should be approached through the dominant national or regional DSOs identified in the country chapter.
- National regulators should be invited to comment on legal or tariff interpretation, especially where collective self-consumption, energy sharing, or REC/CEC implementation is still evolving.

31.20. European research groups and laboratories

The following laboratories and research groups are especially relevant to OpenCEC because they work on electrical energy systems, local energy markets, energy communities, smart grids, distributed optimization, or community-energy governance.

- `G2Elab` (Grenoble Electrical Engineering, Grenoble INP / Université Grenoble Alpes, France).
- `PowerAlps` research community (Université Grenoble Alpes, France).
- `CEA-Liten` (France), especially for local energy systems and distributed flexibility topics.
- `ELECTA` (Electrical Energy Systems and Applications, KU Leuven, Belgium).
- `EnergyVille` (KU Leuven, VITO, imec, UHasselt, Belgium).
- `VITO / Smart Energy and Built Environment` (Belgium).
- `TU Delft` energy-system and energy-hub research ecosystem (Netherlands).
- `Eindhoven University of Technology` energy-system research ecosystem (Netherlands).
- `AIT Austrian Institute of Technology` (Austria), especially smart-grid and flexibility work.
- `DTU` energy-system research ecosystem (Denmark), especially power systems and market design.
- `FSR / Florence School of Regulation` at the European University Institute (Italy), particularly on policy and regulation.
- `RSE` (Ricerca sul Sistema Energetico, Italy), especially for energy communities and Italian regulatory implementation.

- `Politecnico di Milano` energy and power-systems groups (Italy).
- `Comillas ICAI / IIT` (Spain), especially electricity markets, regulation, and power systems.
- `IREC` (Institut de Recerca en Energia de Catalunya, Spain).
- `INESC TEC` (Portugal), especially smart grids, optimization, and energy systems.
- `Fraunhofer IEE` (Germany), relevant for energy systems, digitalization, and local market design.
- `Fraunhofer ISI` (Germany), relevant for policy, transition, and market design.
- `FfE` (Forschungsstelle fur Energiewirtschaft, Germany), relevant to data-driven system analysis.
- `Center for Energy System Intelligence` (`CESI`, Netherlands), relevant to AI and energy-system intelligence.

31.21. Broader research and policy contributors to approach

The review effort should not be limited to electrical engineering. OpenCEC also needs critique from economics, law, political science, digital infrastructure, and commons-governance communities.

- `JRC` (Joint Research Centre of the European Commission), especially where energy-community mapping and policy analysis are involved.
- `European University Institute / FSR` for regulatory and governance review.
- `University groups working on energy justice, commons governance, or platform regulation`, especially where they can test the anti-capture and anti-greenwashing chapters.
- `Public-interest digital-infrastructure researchers` who can challenge identity, interoperability, and protocol-governance assumptions.

31.22. Research topics to seek from laboratories

The academic contribution should be solicited around concrete problem families:

- allocation fairness;
- local market and price-design mechanisms;
- distributed optimization;
- forecasting and uncertainty;
- grid-aware local coordination;
- interoperability and identity federation;
- anti-capture and governance design;
- energy poverty, participation, and social inclusion.

31.23. Review expectations

Each solicited organization should be invited to contribute in one or more of the following modes:

- `factual correction`;
- `legal correction`;
- `grid-operator review`;
- `algorithmic critique`;
- `implementation feedback`;
- `country-note completion`;
- `research partnership exploration`.

OpenCEC should remain open to critique from institutions that may not share all of its assumptions. The objective of this solicitation plan is not consensus for its own sake, but a stronger, more testable, and more European-grade specification.

31.24. Annex H: Operational Volume-Allocation Profile

This annex converts the CLAIRE-1.0 allocation rule into operational controls. It is informed by the `ACC00002764` field workflow but is written as an OpenCEC profile rather than as an instruction to submit data to a particular operator.

31.25. Reference input and output sets

The reference workflow separates immutable source material from derived material.

`R` source set:

- dated perimeter register;
- consumption curve for each consumer delivery point;
- production curve for each production delivery point;
- source manifests and checksum references.

`K` derived set:

- interval allocation in Wh for each beneficiary;
- aggregate consumption, production, allocated volume, and surplus curves;
- transport keys by interval;
- transport payload;
- a human-readable allocation table;
- energy summaries, explicitly marked as derived summaries rather than measurement inputs.

The `R` source set must be immutable after ingestion. The `K` set may be regenerated, but every regeneration must identify the input manifest and allocation version from which it was derived.

31.26. Pre-calculation validation

Before calculating an interval, an implementation must validate:

- exactly one dated perimeter version is selected;
- every active consumer has a consumption value or a declared missing-data status;
- every active producer has a production value or a declared missing-data status;
- all source values use the same interval boundaries and units;
- the active set is derived from dates, not from a historical list of PRMs;
- any delivery point with both producer and consumer roles is represented consistently;
- the selected profile is `CLAIRE-1.0`, with an explicit legal-entity and priority-family configuration.

The calculation must fail closed for a structural inconsistency. It must not quietly turn a missing file, absent timestamp, or unknown participation status into a zero allocation.

31.27. Per-interval conformance test

For every interval t, the implementation must test:

```
0 <= allocation[i] <= consumption[i]                 for every active i
allocation[i] == 0                                   for every inactive i
sum(allocation) <= min(sum(active production), sum(active demand))
surplus == sum(active production) - sum(allocation)
sum(keys) == 100.00 when collectivisable volume > 0
every active consumer has exactly one transport key
no inactive consumer has a transport key
```

The `sum(keys) == 100.00` assertion applies only to the rounded transport representation for a non-zero final assigned volume. The authoritative allocation remains the integer Wh vector.

31.28. Transport adapter profile

The following example is illustrative. It exposes the information an adapter needs without embedding a particular operator's secret, endpoint, or account data.


```json
{
  "protocol_version": "0.1",
  "allocation_version": "DP-WF-0.1+largest-remainder-v1",
  "cec_id": "cec-example",
  "interval_start": "2026-07-01T06:00:00Z",
  "interval_duration_seconds": 900,
  "perimeter_version": "perimeter-2026-07-01",
  "active_consumer_dps": ["dp-a", "dp-b", "dp-c"],
  "production_wh": 900,
  "consumption_wh": 1400,
  "collectivisable_wh": 900,
  "allocations_wh": [
    {"dp_id": "dp-a", "wh": 350},
    {"dp_id": "dp-b", "wh": 350},
    {"dp_id": "dp-c", "wh": 200}
  ],
  "keys_percent": [
    {"dp_id": "dp-a", "key": 38.89},
    {"dp_id": "dp-b", "key": 38.89},
    {"dp_id": "dp-c", "key": 22.22}
  ]
}
```


If the same active set has no collectivisable volume, the adapter must emit one `0.0` key per active delivery point where the receiving interface requires a complete key vector. The adapter may translate this OpenCEC object into a national API payload, but must not delete the original allocation evidence.

31.29. Reconciliation controls

After a complete settlement period, the implementation must reconcile:

- total allocated Wh with the sum of interval allocations;
- total surplus with production minus allocated volume;
- per-delivery-point allocation with the source-window in which that delivery point was active;
- every external submission acknowledgement with the exact payload hash and interval set;
- the number of submitted intervals with the expected calendar count.

For a 31-day month at 15-minute resolution, the expected count is `2,976` intervals. For a 30-day month it is `2,880`. The expected count must be computed from the declared interval and time-zone calendar; it must not be hard-coded as a generic monthly constant.

31.30. Submission discipline

When an external system accepts one interval at a time, an implementation should first submit one non-zero interval and verify the response. It should then submit the complete period exactly once and record progress. It must not launch a second complete submission while the first is still running, because that destroys the evidentiary meaning of the acknowledgement record and can create duplicate or conflicting external state.

The submission log must contain the payload hash, interval count, accepted count, rejected count, first failure if any, response status, and completion time. Credentials, client secrets, and private keys must never be stored in the allocation package or transmitted in an OpenCEC allocation message.

31.31. Reference field evidence and its boundary

The reference ACC workflow successfully submitted all `2,880` quarter-hour intervals for June 2026 and all `2,976` intervals for July 2026, after enforcing the complete active-PRM key vector including `0.0` entries. This is evidence that the adapter rule was necessary for that field interface; it is not proof that every national settlement operator uses the same API or schema.

The workflow also confirms two limitations that an OpenCEC implementation must correct or explicitly constrain:

- a fixed UTC offset is suitable only for a period proven to remain in one offset; the general implementation must use time-zone-aware conversion;
- a delivery-point water-filling script does not implement CLAIRE-1.0 merely because a producer delivery point also appears as a consumer; it must add level 0 by legal entity and the ordered-family stage.

31.32. Annex I: CLAIRE-1.0 Normative Profile

This annex is normative. Together with Chapter 3, it defines the complete `CLAIRE-1.0` profile adopted by OpenCEC 0.1. Chapter 3 states the OpenCEC placement of the rule; this annex specifies the configuration contract, execution state, exception handling, and conformance evidence required to implement it without discretionary interpretation.

In the event of a conflict, the following order prevails:

1. the equations and invariants in Chapter 3;
2. this annex;
3. a declared configuration version;
4. explanatory examples, interface documents, and national transport adapters.

31.33. Scope and explicit exclusions

CLAIRE determines an attributed energy volume for each consumer delivery point and each measurement interval. It is independent of:

- the price, tariff, invoicing, or payment applied after attribution;
- production or consumption forecasts;
- flexibility remuneration or equipment control;
- the network transport, message encoding, storage engine, or user interface;
- the identity, credential, and authorization mechanisms used to access an implementation.

Those layers may use a CLAIRE result, but they must not change it. In particular, a price signal, forecast, market offer, contractual preference, or later device action must never modify an already determined CLAIRE volume for the same measurements and configuration.

The computation is stateless between intervals. No result from a previous interval, forecast, accumulated balance, hidden score, or unrecorded operator decision may influence the calculation for interval t. A correction is not a hidden state: it is a new, explicitly versioned calculation based on a declared corrected input set.

31.34. Normative principles

31.34.1. Determinism

For identical measurements, dated perimeter, legal-entity mapping, family configuration, CLAIRE version, precision, and rounding rule, two conformant implementations must produce exactly the same Wh vector, family breakdown, surplus, and transport-key vector.

31.34.2. No individual allocation coefficient

CLAIRE must not use an individual allocation coefficient, consumption share, capital contribution, bilateral preference, discretionary score, or opaque preference function. A person may be represented in the legal-entity mapping and a delivery point may be represented in a priority family, but neither fact authorizes the runtime to select a bespoke volume.

31.34.3. Separation of governance and execution

Governance defines legal entities, family membership, priority order, effective dates, precision, and versioning before an interval is processed. Execution applies the fixed mathematical rule to measurements. A PMO, operator, or service provider may administer the configuration under its governance mandate; it must not choose attributed volumes after observing measured production or consumption.

31.34.4. Producer neutrality after level 0

After every entity has completed level `0`, residual production belongs to a single numerical reservoir. The residual producer identifier must not influence family processing. No bilateral producer-to-consumer association may be restored at this stage.

31.34.5. Equality within a call

Within one water-filling call, every non-saturated eligible delivery point receives the same additional volume. CLAIRE equalizes additional Wh, not percentages of consumption and not final self-consumption rates. A smaller consumer may reach its cap earlier; this is saturation, not a preferential allocation.

31.35. Rationale and prohibited substitutes

This section is informative, but it explains the boundary of the normative rule.

31.35.1. Static coefficients

A static coefficient reserves a fixed production share for each consumer before the interval measurements are known. It cannot react to a consumer whose demand is zero or lower than its reserved share, and it risks leaving another active consumer underserved while eligible production is available. A static coefficient is therefore not a substitute for CLAIRE unless it is merely a transport representation of a CLAIRE result already calculated for the same interval.

31.35.2. Dynamic coefficients without a public rule

A dynamically generated percentage may react to measurements, but a sequence of numerical keys is not, by itself, an allocation specification. Without the dated perimeter, legal-entity mapping, family configuration, algorithm version, precision rule, and replay data, a third party cannot determine whether two equal situations received equal treatment. CLAIRE governs the rule that produces a key; it does not merely publish the key.

31.35.3. Bilateral allocations after mutualisation

After level `0`, restoring a direct producer-to-consumer association would let the origin of residual production select beneficiaries. That would contradict producer neutrality and make the collective phase dependent on bilateral arrangements. A later settlement or contractual layer may record who financed an asset or supplied a service, but it must not alter the CLAIRE volume result after mutualisation.

31.35.4. Equal Wh versus equal rate

CLAIRE distributes an equal additional volume among non-saturated members of one water-filling call. It does not equalize the percentage of each member's consumption that is covered. For demands of `2 Wh` and `6 Wh` with `4 Wh` available, CLAIRE assigns `2 Wh` to each. The resulting coverage rates are `100%` and approximately `33.33%`. This is an intended result: the smaller demand has reached its physical cap and cannot receive more.

31.36. Normative configuration object

The configuration effective at the start of interval t must contain all fields below. Implementations may add fields, but may not omit or change the meaning of these fields.

```
{
  "claire_version": "CLAIRE-1.0",
  "configuration_id": "claire-config-2026-08-07",
  "effective_from": "2026-08-07T00:00:00Z",
  "effective_until": null,
  "energy_unit": "Wh",
  "integerization_rule": "largest-remainder-canonical-id-v1",
  "entities": [
    {
      "entity_id": "entity-a",
      "producer_dps": ["dp-production-a"],
      "consumer_dps": ["dp-consumption-a-1", "dp-consumption-a-2"]
    }
  ],
  "priority_families": [
    {
      "family_id": "family-1",
      "priority": 1,
      "consumer_dps": ["dp-consumption-b-1"],
      "effective_from": "2026-08-07T00:00:00Z",
      "effective_until": null
    }
  ],
  "overlap_rule": "highest-priority-family-only"
}
```

The configuration must ensure that every active production and consumer delivery point has an unambiguous role. A delivery point may produce and consume; its production and consumption values remain distinct input series. A consumer delivery point may appear in an entity and in a priority family because those appearances apply to different levels. It must not be assigned to more than one active family unless a later OpenCEC version standardizes another overlap rule.

An implementation must reject the interval when:

- no configuration version covers the interval start;
- more than one configuration claims the same interval without a declared precedence;
- a delivery point identifier is ambiguous;
- a required active measurement is absent, negative, or non-numeric;
- the input measurement precisions or interval boundaries are incompatible;
- an entity or active family refers to a delivery point outside the dated perimeter;
- the overlap rule cannot select one family unambiguously.

31.37. Required execution state

For each interval, the implementation must retain the following values, even if its public interface shows only a final key:

- `A[i]`: total attributed Wh at consumer delivery point `i`;
- `A0[i]`: Wh attributed to `i` in level 0;
- `X[k][i]`: Wh added to `i` by priority family `k`;
- `P_entity[e]`: total measured production of entity `e`;
- `P_residual[e]`: production of entity `e` remaining after level 0;

- `E_collective`: collective reservoir after mutualisation and after each family;
- final surplus;
- accepted or rejected status and the exact reason where the interval cannot be calculated.

The public result must retain the decomposition. A final value alone is insufficient because it cannot distinguish level-0 self-consumption from a later family allocation.

31.38. Normative execution procedure

The following procedure is normative. Equivalent implementations are permitted only if they produce the same result and evidence.

```
validate(measurements, dated_perimeter, claire_configuration)

for each active consumer delivery point i:
    A[i] = 0
    A0[i] = 0
    for each priority family k:
        X[k][i] = 0

for each legal entity e in canonical entity-id order:
    P_entity[e] = sum(measured production of active producer DPs of e)
    I_entity[e] = active consumer DPs of e
    level0_increment = WATER_FILL(I_entity[e], residual capacities C[i], P_entity[e])
    A[i] = level0_increment[i] for i in I_entity[e]
    A0[i] = level0_increment[i] for i in I_entity[e]
    P_residual[e] = P_entity[e] - sum(level0_increment[i])

E_collective = sum(P_residual[e])

for each active priority family k in increasing priority order:
    I_family[k] = eligible consumer DPs of k with C[i] - A[i] > 0
    family_increment = WATER_FILL(I_family[k], capacities C[i] - A[i], E_collective)
    A[i] = A[i] + family_increment[i] for i in I_family[k]
    X[k][i] = family_increment[i] for i in I_family[k]
    E_collective = E_collective - sum(family_increment[i])
    if E_collective == 0:
        stop family processing

surplus = E_collective
return A, A0, X, P_residual, surplus, metadata
```

The use of a canonical order in this pseudo-code is only for reproducible iteration and logging. The mathematical result must remain invariant under permutation of producer, consumer, entity, and input-record ordering.

31.39. Water-filling contract

For a finite eligible set I, non-negative capacities R_i, and available energy E, define:

$$D = \min\left(E, \sum_{i \in I} R_i\right).$$

If I is empty or $D = 0$, every incremental volume is zero. Otherwise there is a unique $\lambda \geq 0$ such that:

$$\sum_{i \in I} \min(R_i, \lambda) = D.$$

The incremental volume is:

$$X_i = \min(R_i, \lambda).$$

The remaining energy after this call is:

$E' = E - \sum_{i \in I} X_i.$

These equations are the sole definition of water filling in CLAIRE-1.0. An iterative, sorting-based, vectorized, or closed-form implementation is conformant only if it produces this solution before integerization.

31.40. Edge conditions

31.40.1. Zero energy and empty sets

If available energy is zero, every incremental volume is zero. An empty family and a family with no positive residual capacity are skipped. An entity without a consumer delivery point sends all its production to the collective reservoir. An entity without production creates no level-0 volume.

31.40.2. Production exceeding accessible demand

If production exceeds the sum of the capacities reachable under level `0` and the configured families, the remainder is surplus. CLAIRE must not allocate the remainder to a consumer outside the selected family sequence merely to eliminate surplus.

31.40.3. Configuration changes

The configuration selected for an interval is the one effective at the interval start. A later change must not alter past intervals except through a separately versioned correction. A correction result must identify both the superseded allocation and the replacement allocation.

31.40.4. Precision and integerization

The canonical accounting unit is Wh. An implementation may use higher internal precision but must publish it. If a result is emitted in integer Wh, it must first calculate the real-valued CLAIRE result, truncate no beneficiary above its capacity, then distribute the remaining Wh by decreasing fractional remainder. A tie must be resolved by the published canonical stable identifier. After integerization, conservation and all individual bounds must still hold.

The canonical identifier tie-breaker is not a family priority and must never be used before the exact water-filling solution. It resolves only an indivisible representation remainder.

31.40.5. Percentage-key representation

National interfaces may require percentage keys. The percentage key is a post-processing representation of final attributed Wh, not an alternative allocation rule. For a non-zero final attributed total, the rounded keys must total exactly `100.00`; for a zero final total, every active consumer key is `0.0`. An adapter that requires one key per active consumer must include active zero-key delivery points and omit inactive delivery points.

31.41. Worked normative cases

The cases below are normative for the stated inputs. They make the level boundary, saturation behavior, and strict family ordering independently testable. Values are stated in kWh for readability; a production implementation applies the same logic in its declared Wh precision.

31.41.1. Case N1: two consumers, one water-filling call

The eligible consumer set contains `A` and `B`. Their residual capacities are respectively `2` and `6`; the available energy is `4`.

Delivery point	Capacity	Attributed volume	Coverage rate
`A`	`2`	`2`	`100 %`

B	6	2	33.33 %

The unique filling level is 2. Both delivery points receive the same increment. The calculation does not allocate the remaining theoretical capacity of B because no energy remains.

31.41.2. Case N2: successive saturation

The eligible capacities are `(2, 5, 10)` and the available energy is 9. The first equal layer is 2 for every delivery point. A is then saturated; the remaining 3 is shared between B and C.

Delivery point	Capacity	First layer	Second layer	Final volume
A	2	2	0	2
B	5	2	1.5	3.5
C	10	2	1.5	3.5

No entry order can change this result. B and C are not saturated and therefore receive the same second increment.

31.41.3. Case N3: strict family priority

Assume the level-0 stages have produced a collective reservoir of 7. Family 1 contains A and B with residual capacities 2 and 3; family 2 contains C with residual capacity 10.

Stage	Eligible set	Reservoir before	Attributed result
family 1	A, B	7	A = 2; B = 3
family 2	C	2	C = 2

C must not receive an increment before both A and B are saturated. A family order is therefore a governance choice with measurable effect and must be effective before the interval begins.

31.41.4. Case N4: level 0 before mutualisation

Entity E1 has production 6 and two consumer delivery points A and B with demands 2 and 3. Entity E2 has one consumer delivery point C with demand 10 and no production. The level-0 call for E1 attributes 2 to A and 3 to B. Its residual production is 1. Only this 1 enters the collective reservoir and may subsequently be attributed to C through an eligible family.

Entity or stage	Production / reservoir	Attributed volume	Residual
E1 level 0	6	A = 2; B = 3	1
mutualisation	1	none	1
family containing C	1	C = 1	0

It would be non-conformant to allocate any part of E1's 6 to C before A and B have completed E1's level-0 call.

31.41.5. Case N5: producer fragmentation neutrality

Suppose that, after level 0, the collective reservoir is 10. Replacing one residual producer measurement of 10 by two residual producer measurements of 3 and 7 must not affect the family results. The family stage receives only the scalar reservoir total, not an ordered list of producer identities.

31.42. Result and audit object

The following fields must be exportable per interval in a documented machine-readable format:

- interval start, end, duration, local time-zone identifier, and UTC representation;
- agreement or CEC identifier;
- CLAIRE version, configuration identifier, and configuration hash;
- dated-perimeter version and input-measurement identifiers or hashes;
- each entity's measured production, level-0 output, and residual production;
- collective reservoir before and after every family;
- every family's identifier, priority, eligible set, and incremental Wh output;
- final Wh vector, final percentage-key vector when applicable, and final surplus;
- internal precision, integerization method, and percentage-rounding method;
- correction or rejection status, with a reason when applicable;
- integrity proof, calculation timestamp, and executable or source-code identifier.

An auditor must be able to reconstruct the result without access to an operator's private database, secret, password, or mutable dashboard state. Personal information not required to replay the allocation must be pseudonymized or omitted from the exported trace.

31.43. Example calculation trace

For one completed interval, a human-readable trace should let a participant or auditor follow the result without reverse engineering a key vector. The trace should state, in this order:

1. the interval, applicable time zone, measurement status, and configuration version;
2. the active delivery-point set and each legal entity's production and consumption input;
3. the level-0 result of every entity, including every attributed Wh and each residual production;
4. the collective reservoir at mutualisation;
5. each family in priority order, its eligible residual-capacity vector, the water-filling increment, and its post-family reservoir;
6. final delivery-point volumes, surplus, integerization changes if any, and transport keys;
7. the content hashes and calculation identifier needed to reproduce the trace.

The trace must make explicit a zero result caused by zero production, zero demand, no eligible family, an inactive delivery point, or an invalid rejected interval. These outcomes have different meanings and must not be represented by the same unexplained zero.

31.44. Conformance methodology

An implementation conforms to CLAIRE-1.0 if and only if it:

- executes level 0 separately for every legal entity before mutualisation;
- completely mutualises residual production before the first family is processed;
- applies the water-filling equations at every level;
- processes effective families in strict priority order;
- respects all individual bounds, conservation identities, and rounding rules;
- produces the required execution state and metadata;
- passes the official cases in Chapter 3 and randomized differential tests against a reference implementation.

Randomized testing must include at least the following properties:

- non-negativity of every intermediate and final volume;
- no delivery point receives more than its measured consumption;
- no family receives volume before an earlier unsaturated family while reservoir energy remains;
- sum of entity residuals equals the reservoir at mutualisation;
- final attributed volume plus surplus equals total production;

- permutation of the input record ordering changes neither identifier-to-volume association nor surplus;
- splitting one producer's production into fragments after level 0 does not change the collective result;
- repeated execution with the same inputs is bit-for-bit identical after declared rounding.

31.45. Evolution rule

Any successor to CLAIRE-1.0 must publish the problem it addresses, the results that can change, the compatibility relationship, new edge conditions, and additions or changes to the conformance suite. It must not introduce an undisclosed individual coefficient, a producer-consumer link after level 0, an input-order dependency, an ex-post operator decision, or unequal treatment among non-saturated members of the same family.

31.46. Annex J: Conformance, Release, and Editorial Control

This annex is **NORMATIVE** for a release claiming a named OpenCEC profile.

31.47. Required release manifest

Each official PDF and source distribution must contain or reference a manifest with: `document_version`, `subversion`, `distribution_commit`, `baseline_commit` if any, `build_date`, `build_tool_version`, `source_sha256`, `pdf_sha256`, `profile_versions`, `test_suite_versions`, `known_limitations`, `license`, `change_log`, and a security-report contact. The distribution commit is the exact commit from which the released artefact was built. It must not be replaced by a historical baseline identifier.

31.48. Required profile declaration

An implementation or report claiming conformance must declare one of the following statuses for every profile: `conformant`, `not implemented`, `experimental`, `not applicable`, or `deviation`. A deviation must name the failed requirement, operational effect, affected participants, mitigation, expiry date, and accountable decision-maker. A marketing label must not hide a deviation.

31.49. Minimum verification gates

Before publication, the maintainer must verify:

1. all references, annex labels, and profile names resolve unambiguously in the compiled PDF;
2. every normative requirement has a stable identifier or an unambiguous profile location and a test or review method;
3. CLAIRE conformance vectors and randomized invariants pass when the profile is claimed;
4. SIGL adversarial tests pass when the profile is claimed;
5. a price statement identifies its accounting boundary when pricing is shown;
6. legal and national-profile assumptions are dated and disclosed;
7. the source and generated PDF hashes match the published manifest;
8. the complete PDF has been visually reviewed for clipping, empty accidental pages, broken tables, and inaccurate headers or footers.

31.50. Editorial requirements

Every chapter title must have a unique number in the compiled document. Annex letters must be unique. Cross-references must use generated labels or stable names rather than fragile hand-maintained section numbers. A document using a `draft` version must identify the open questions and must not present experimental interoperability or future research as deployed capability.

31.51. Changelog for v3

Version `0.1-draft v3` introduces the document-status convention; explicit conformance profiles; the price-and-settlement boundary; the SIGL trust and assurance profile; CLAIRE edge-condition requirements; public-interest claim discipline; and a release manifest. It also corrects the duplicate Annex H label and replaces fragile numeric references in the compliance summary with stable chapter names.

31.52. Annex K: Use Case on Small Ground-Mounted PV and Progressive Citizen Investment

This chapter explains why small ground-mounted photovoltaic systems, with or without batteries, can form a robust and progressive asset base for citizen energy communities.

31.53. Core thesis

Small ground-mounted photovoltaic systems have a particularly valuable property for an energy community: they transform an understandable investment into a relatively predictable energy volume.

This predictability does not mean the absence of weather variability. It means that, at the scale of a portfolio of simple, well-sized, and properly operated assets, the relationship between installed capacity, expected production, maintenance, and use value remains intelligible to citizens.

31.54. Why this matters

Compared with more financialized or capital-intensive structures, small ground-mounted PV can support:

- gradual deployment;
- modular ownership;
- repeated learning;
- distributed risk;
- local appropriation of technical and economic choices.

31.55. With or without battery

31.55.1. Without battery

Without a battery, small ground-mounted PV already makes it possible to:

- create a tangible and visible asset;
- produce predictable volumes over the long term;
- begin with relatively accessible investment amounts;
- support collective self-consumption or energy-sharing logics;
- build an equipment trajectory through increments.

31.55.2. With battery

With a battery, the system gains a new layer of value:

- time-shifting part of production;
- better matching with certain consumption profiles;
- potential reduction of curtailment;
- contribution to local flexibility;
- access to finer price and balance signals.

The battery should nevertheless remain justified by actual operational value and not by symbolic sophistication.

31.56. Progressive investment logic

One of the major strengths of this asset family is that it enables progressive two-digit investment steps, meaning a gradual build-up through modest increments without necessarily depending on heavy bank financing from the outset.

This progressive logic may include:

- a first installation financed by a small number of citizens;
- incremental extension by repeated subscriptions;
- later addition of storage;
- replication across several local sites;
- direct reinvestment of part of the generated value into new assets.

31.57. Banking independence

The important point is not to exclude banks on principle. It is to avoid making them a condition of possibility from the very beginning.

When early-stage deployment can begin with manageable unit sizes, communities gain:

- more autonomy in timing;
- less dependence on external risk filters;
- more room for citizen learning;
- better ability to test governance and allocation rules before scaling.

31.58. Constant yield-to-volume intuition

For citizen pedagogy, it is essential to be able to say something simple: adding a small unit of capacity adds an order of magnitude of expected production that remains understandable.

That pedagogical regularity is valuable because it lets participants reason in concrete terms:

- how many kW are financed;
- what annual kWh volume this roughly corresponds to;
- what share can be self-consumed or shared;
- what battery capacity may later become useful.

31.59. Relevance for OpenCEC

OpenCEC should be compatible with highly modular portfolios of local assets, including:

- small PV fields;
- shared batteries;
- incremental hybrid systems;
- mixed household and municipal participation.

This makes the protocol relevant not only for large flagship projects but also for a granular path of community build-out.

31.60. Anti-greenwashing implication

Small ground-mounted PV is also interesting because it forces concreteness. One is speaking about an identifiable machine, a site, a power rating, a production profile, maintenance, usage, and allocation.

That materiality reduces the rhetorical space available for vague promises. It therefore supports the OpenCEC requirement that every term used must translate into rights, volumes, and the wallets of participating citizens.

31.61. Planned extensions

- Economic model examples for modular citizen financing.
- Battery decision framework based on local profiles.
- Comparative analysis with rooftop-only and large centralized projects.