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SysML Modeling of Digital Twins for Renewable Energy Communities

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DTE Workshop - AEiC 2026

Introduction

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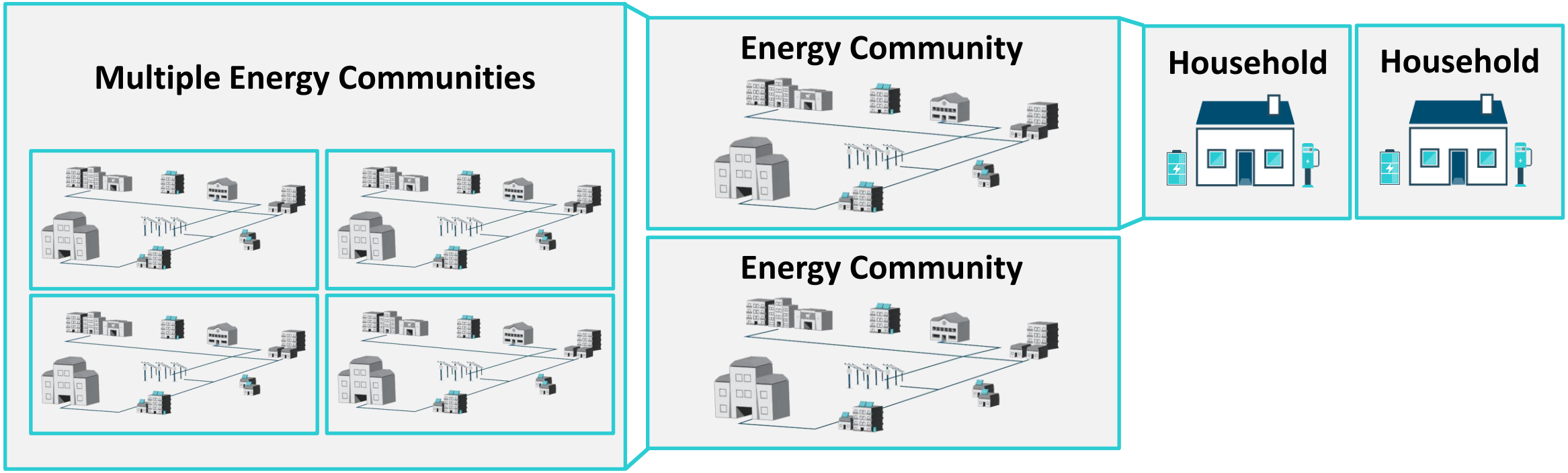
- RECs enable local consumers and prosumers to pool their devices for sharing energy and participating in grid-level demand response.
- A REC can be managed with monitoring diverse IoT devices, honoring member contracts, and meeting regulatory limits.
- Digital Twins (DTs) are real-time virtual counterparts of physical devices, aggregating measurements, exposing controllable set-points, and enabling optimization and predictive maintenance.
- MBSE and Model-Driven Digital Twin Engineering can be used to prevent the system from becoming a point-to-point integration effort.

Introduction



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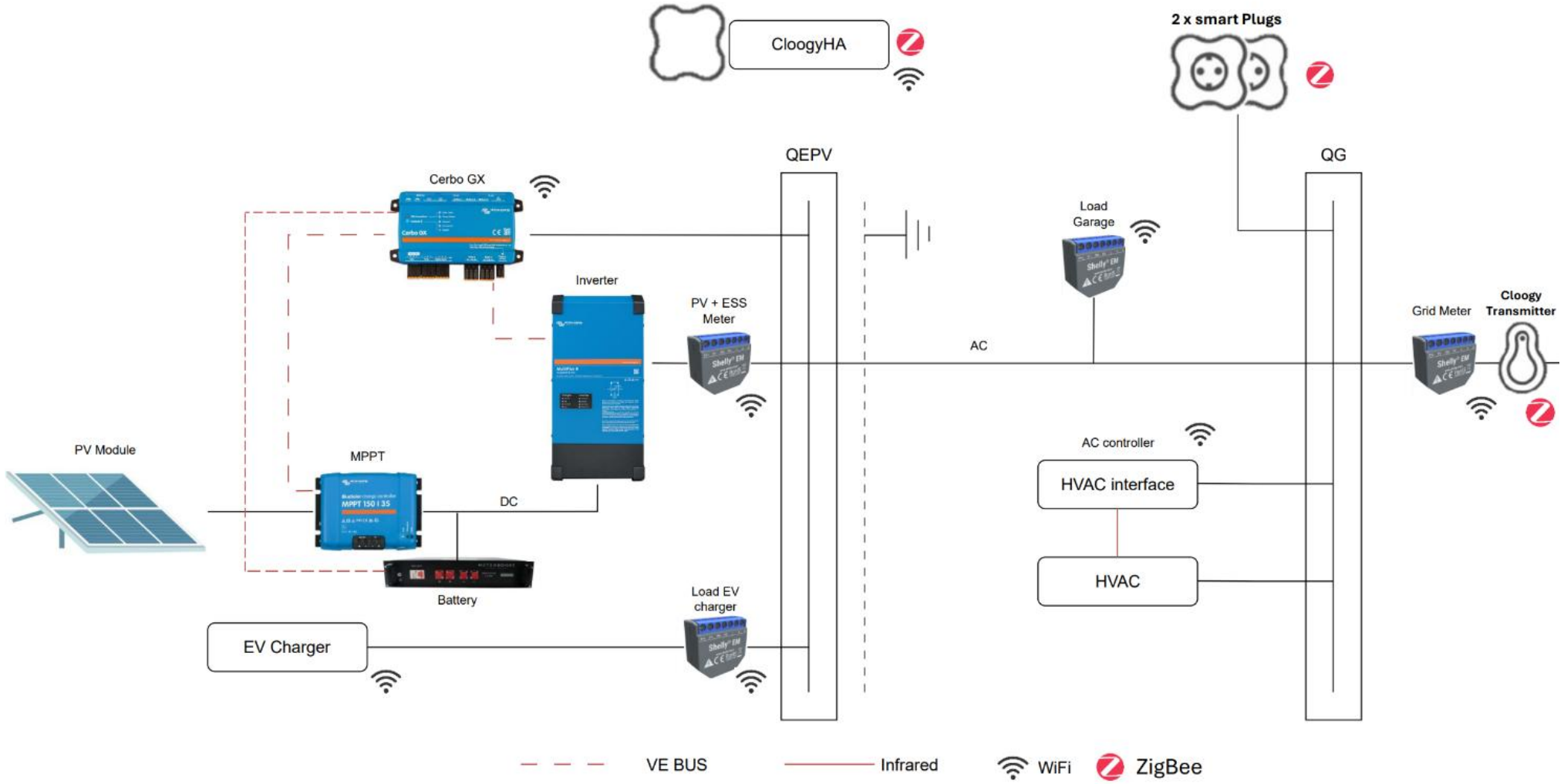


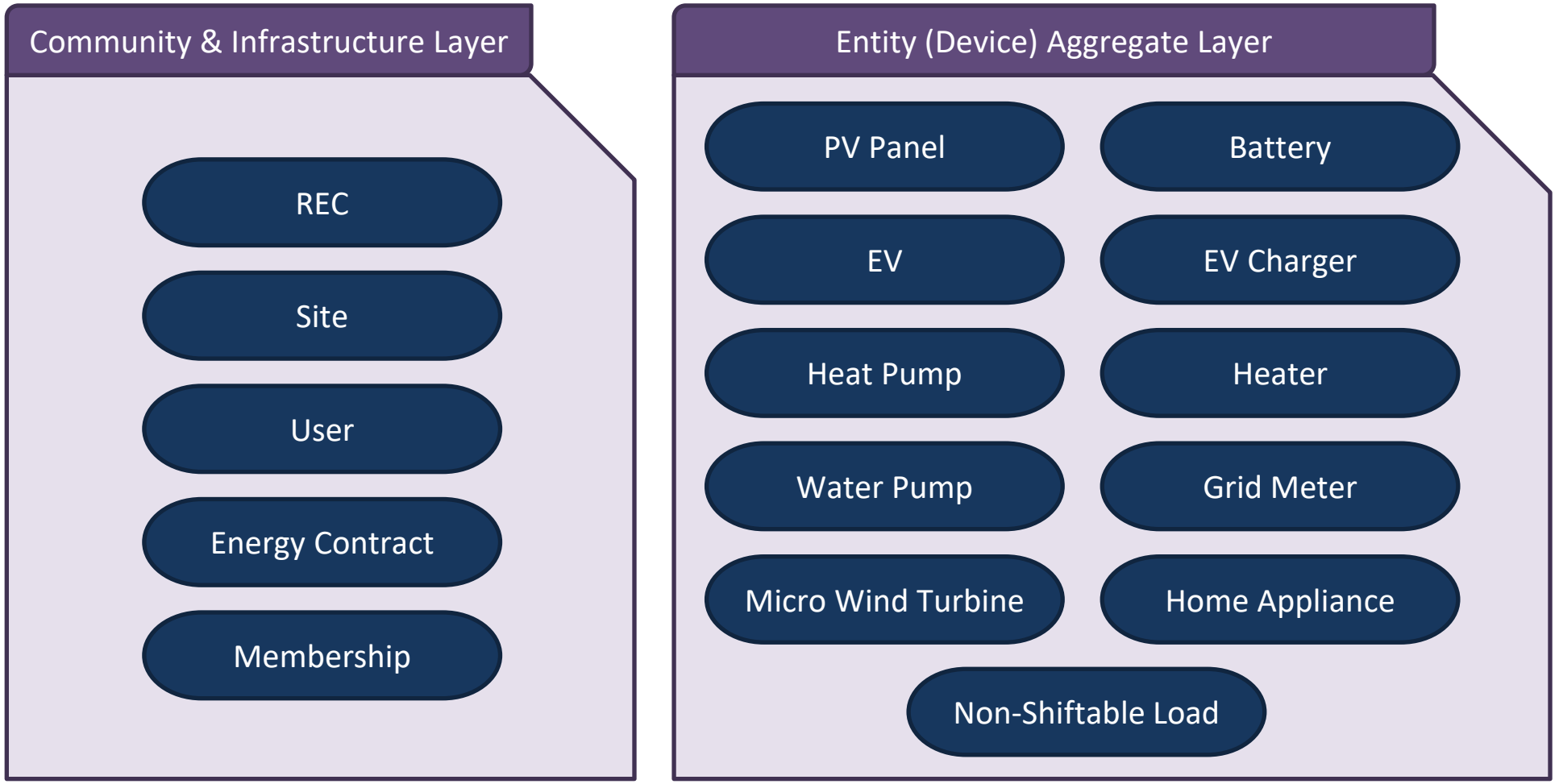
Contributions

Contributions

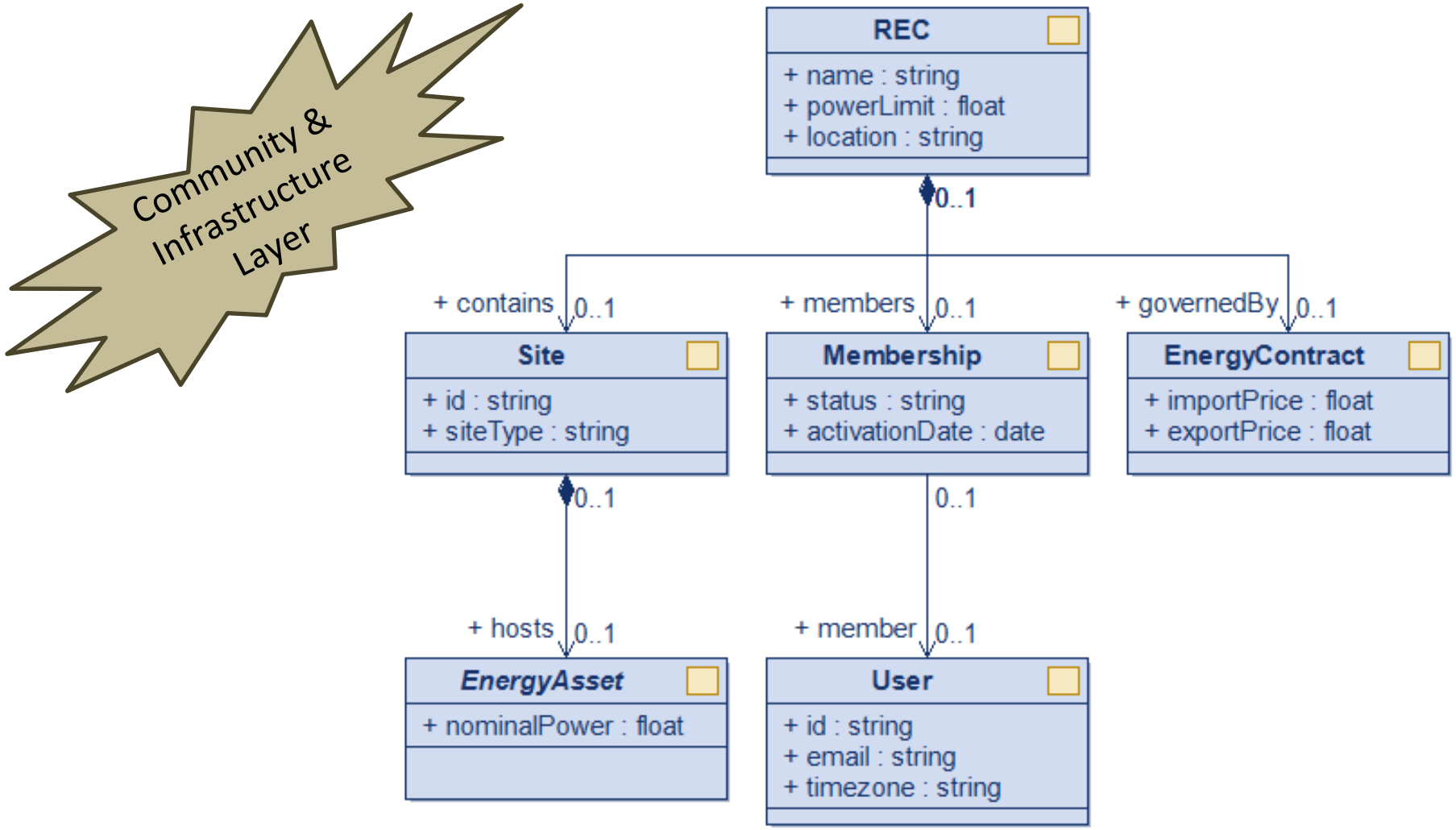
- Modeling the organizational layer and the energy assets using Modelio based on a real-world use case.
- Identification of four semantic gaps in SysML and introduction of the SAREF4ENER ontology as a reference to fill them.
- Addressing a DT engineering workflow for RECs with different IoT energy devices.

Proposed Modeling

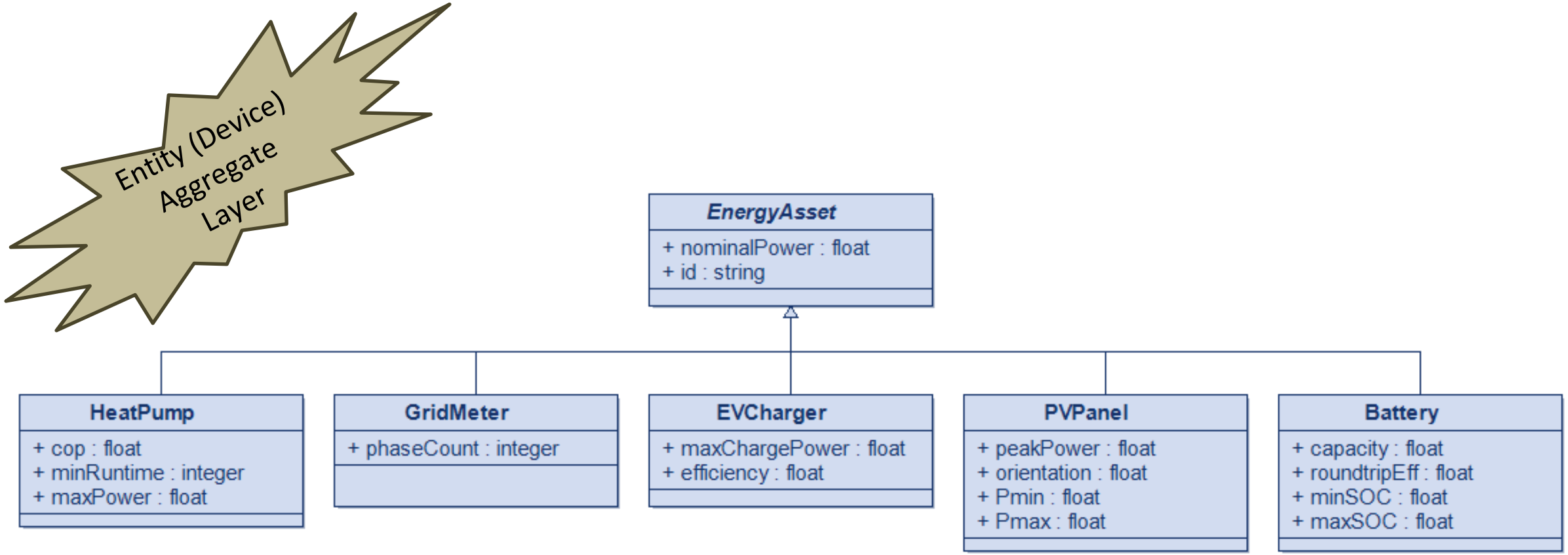
Proposed Modeling (REC Domain Model)



Proposed Modeling (SysML Expression in Modelio)



Proposed Modeling (SysML Expression in Modelio)



Household Scenario

Household Scenario (Example)

- We consider a single household that is a member of a REC and owns: a 5 kWp rooftop PV system, a 10 kWh lithium battery, an 11 kW EV charger, and an air-to-water heat pump for heating and domestic hot water.
- The household pays time-of-use tariffs and participates in a demand-response program with the REC aggregator.

Representation of the *EVCharger* device in JSON format


```json
{
    "policyId": "my.test:policy",
    "attributes": {
        "name": "EVCharger",
        "model": "Cloogy(r) Plug",
        "manufacturer": "CleanWatts",
        "serial number": "100",
        "location": "Ground floor"
    },
    "features": {
        "nominalPower": {
            "properties": {
                "value": 0.045,
                "unit": "kW"
            }
        },
        "maxChargePower": {
            "properties": {
                "value": 0.1506,
                "unit": "kW"
            }
        },
        "efficiency": {
            "properties": {
                "value": 80,
                "unit": "%"
            }
        }
    }
}
```

Household Scenario (Standards)

SysML v2

A JSON metamodel for device specifications enhances interoperability and supports bidirectional data exchange with other engineering tools.

Asset Administration Shell (AAS)

Cleanwatts devices currently utilize IoT and cloud architecture. But SysML2AAS will prospectively automate SysML v2 to AAS transformation for Industry 4.0 compatibility.

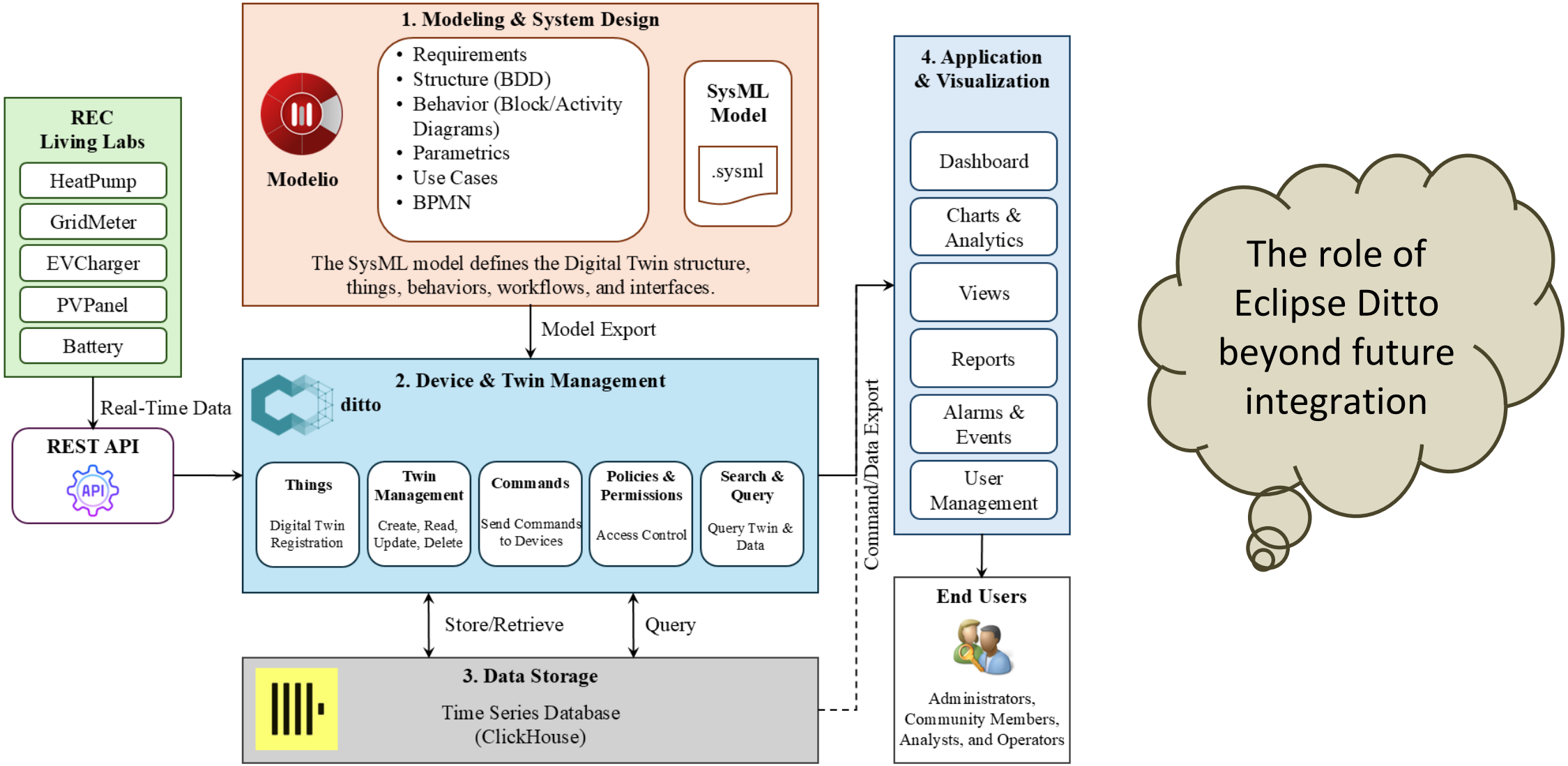
Digital Twins Definition Language (DTDL)

DTDL is generally used in our Digital Twins model for RECs, as device specifications and configurations are represented in JSON/YAML format.

Next Generation Service Interface with Linked Data (NGSI-LD)

Our proposed framework utilizes REST API for obtaining real-time data from Cleanwatts labs via JSON, integrating physical and virtual systems with knowledge graphs.

Household Scenario (System Architecture)



The role of Eclipse Ditto beyond future integration

Discussion

Discussion: Gaps and the SAREF Bridge
(Semantic Gaps in Plain SysML for REC Modeling)

	Gap	Consequence
G1	Plain classes, no ontology anchor	No cross-system recognition of "Battery" as s4ener:Storage
G2	Free-text sensor/actuation labels	Same concept named differently across models
G3	No flexibility / DR model	Cannot express REC contractual flexibility
G4	No runtime link	Design-time only, disconnected from the live state

A SysML model captures *structure* – blocks, attributes, and associations – but does not, by itself, carry *semantics* understandable to third-party energy management systems. By inspecting the proposed model against the needs of a REC Digital Twin, we identify four gaps.

Discussion: Gaps and the SAREF Bridge

(Sketched mapping from SysML blocks to SAREF4ENER concepts)

SysML Block	SAREF / SAREF4ENER Class	Profile
PVPanel	s4ener:PowerGenerator	PowerEnvelope
Battery	s4ener:Storage	FillRate
EVCharger	s4ener:LoadDevice	Power
HeatPump	s4ener:LoadDevice	DemandDriven
GridMeter	saref:Meter	IncentiveTable

The SAREF ontology family and its SAREF4ENER extension address G1–G3, providing a shared vocabulary for devices, measurements, commands, and flexibility profiles, by importing this extension as a dedicated *reference package* in the same Modelio project. Gap G4 – the runtime link – is also addressed by complementary work on DT platforms, such as Eclipse Ditto.

Summary

Summary

- Used SysML in Modelio for household representation using two Block Definition Diagrams: device taxonomy and organizational view.
- Identified four semantic gaps in SysML and proposed SAREF4ENER ontology, imported as a reference package, for closure.
- Presented a Model-Based Systems Engineering workflow for Digital Twins of Renewable Energy Communities.
- The ongoing work also aims to fill the fourth gap – generating Eclipse Ditto Thing definitions based on the annotated SysML model.

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Thank You!

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Find the MATISSE project here.

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