Work Package Technological Translation | Requirement Analysis

Deliverable 2.1: Technical report on best practices for market coupling of distributed assets

Partner responsible: Next Kraftwerke Benelux
Partners involved: Next Kraftwerke Benelux, EnergieID

Authors: Elias De Keyser, Vincent Dierickx, Jan Pecinovsky and Laura Van den Berghe (alphabetical order)

This document is a deliverable of the FlexSys project (A Flexible electricity System contributing to security of supply) funded by the Energy Transition Fund of the Belgian federal government, managed by the FPS Economy, SMEs, Self-employed and Energy.

Contents

1. Introduction

This report covers deliverable 2.1 'Technical report on best practices for market coupling of distributed small assets', which is part of Work Package (WP) 2 'Technological Translation'. In WP2, a Proof of Concept will be developed to test the theoretical foundations concerning residential flexibility provision, demonstrate its technological feasibility and accelerate its market uptake. Concretely, the PoC will translate the theoretical control strategies (WP1) and market strategies (WP 3) into a useable technological design able to control different assets (PV, HP, EV etc.) for different market purposes. This deliverable contains the first step in the creation of the PoC, as it reflects on and describes the technical requirements of the technological design for different market scenarios.

This deliverable is built up as follows. Section 2 describes two relevant market scenarios in which the PoC can be tested. As such, the testing conditions and set-up of the PoC reflect the real-world conditions as much as possible, increasing its value. Section 3 provides an overview of the components of the technological design and the requirements for their coupling.

2. Flexibility strategies

Residential flexibility can be valorised in different ways and on different markets (see deliverable 3.6).

Implicit flexibility entails a household's reaction on time of use prices and is most relevant for day–ahead, intraday markets and imbalance markets. Explicit flexibility concerns being steered by a flexibility service provider for the delivery of ancillary services on the reserve power markets (FCR, aFRR and mFFR). Below we provide a brief overview of the most important technical considerations when providing flexibility services on the energy markets. For a more extensive overview, we refer to deliverable 3.6.

For each flexibility market, we considered 3 technical properties:

- **How frequent do local measurements need to be provided to the *upstream processes (i.e.* Aggregation and Dispatching components in COFYcloud, VPP Dispatching in NextCloud and Verification by Elia*)*** ? This property is of technical relevance: when the required granularity and frequency of the data transmissions can be expressed in terms of *minutes*, both the COFYbox and the aggregating cloud services can rely on architectures using queued processing of HTTP-requests, which require less technical overhead than the alternative. When the required frequency of data transmissions goes up towards *seconds*, a pipelined architecture using real-time streaming analytics becomes necessary, which has a much larger technical overhead.
- **What form does the *Flexibility Signal* take**? Most household assets can only provide binary flexibility (turn on or off). This makes implementing an explicit flexibility signal, one that may require a specific power set point or ramp rate, a challenging task that can only be accomplished by cleverly dispatching many distributed assets. Meanwhile, an implicit price signal rewards the *best effort* an asset can provide, making it much more *low tech* and scalable.
- **What data is required to *verify* the delivered flexibility**? Here, 15-minute measurements by the DSO-installed Digital Meters have a clear advantage over any other system: the infrastructure is already in place, data is measured by an independent party, and regulation already allows this data to be used for financial settlement between energy suppliers and clients.

Table 1: Technical considerations			
Product	**Upstream Data**	**Flexibility Signal**	**Verification Data**
FCR	2 s	Local frequency measurement – Power ramp rate	Ex-post and real-time to Elia
aFRR	4 s	Power set point	Via Upstream Data
mFRR	15 min	Power set point	DSO Digital Meter
Imbalance Steering	5-15 min	Price	DSO Digital Meter

In conclusion: mFRR and Imbalance Steering both have an *upstream data requirement* of 5 to 15 minutes and can be verified by using the DSO's Digital Meters. This makes them the most accessible products for residential flexibility, which in turn improves the chances for replicability and scaling.

Based on the existing valorisation strategies for residential flexibility and an analysis of the technical specifications per flexibility product, we propose to develop and test two flexibility strategies as part of the PoC:

- **Implicit flexibility strategy**:

  This strategy entails price optimisation of a dynamic day-ahead based tariff, with additional price incentives based on imbalance and intraday prices.

- **Explicit flexibility strategy**:

  This strategy includes explicit asset steering for the mFRR product and is based on a flex schedule. Flexibility is remunerated by an additional fee, on top of the dynamic price. How this fee will be designed, invoiced and settled between aggregator, community and household, is not part of this deliverable (see deliverables 3.3 and 3.5). AFRR services will be considered in this strategy when the technical specifications require less urgency and accuracy.

3. Technical design

Our technical design for the market uptake of residential flexibility includes 4 building blocks, their technologies, and the connections between these technologies (see Figure 1):

- Flexible assets of households, including PV invertors, electric vehicles, heat pump and home batteries.
- The community flexibility platform, including the COFY box and cloud developed by EnergieID to aggregate flexibility at the residential level.
- The Virtual Power Plant (VPP) of a large-scale aggregator, I.e. Next- Kraftwerke to further aggregate the flexibility such that it can be brought to the market.
- The market platform, either controlled by market operators (e.g. EPEX) or by Elia (e.g. ancillary services).

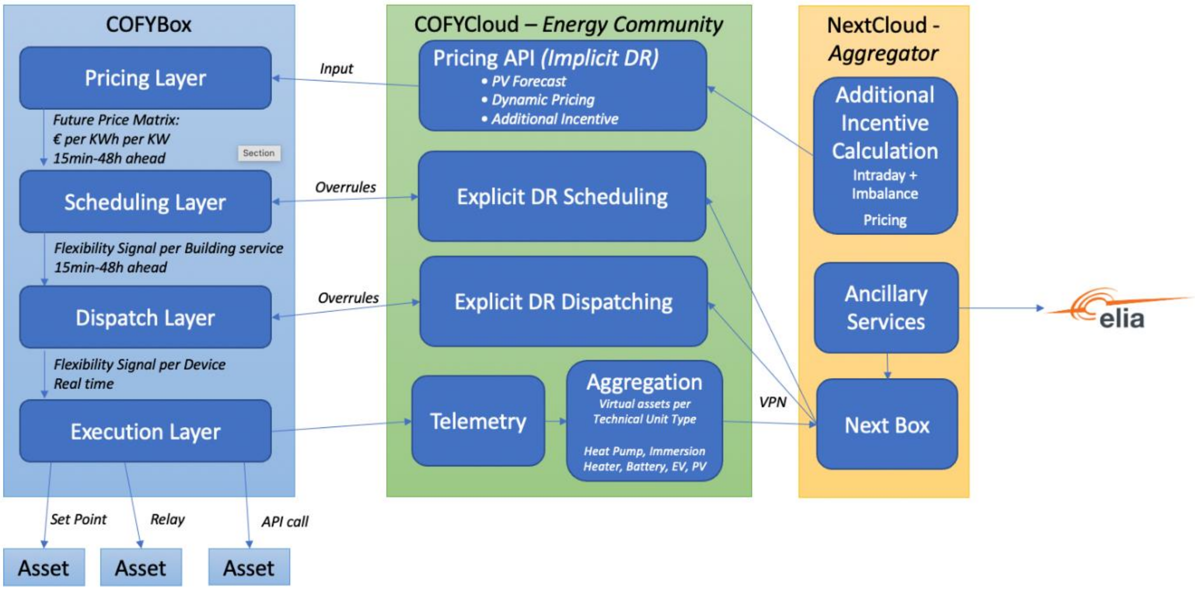

Figure 1: Technical design for the market uptake of residential flexibility

In this section, we will first discuss the individual technologies as components of the technical design. Next, we elaborate on the requirements to connect these components with each other.

3.1. Components

Below, the different components of the technical design will be discussed in more detail.

3.1.1. Household assets

In the pilot, the following assets will be integrated:

- 15 (PV + home battery + P1-dongle)
- 4 (PV + electrical boiler + P1-dongle) (of which for 1 it is not sure yet whether this asset will participate in the asset steering)
- 9 (PV + heat pump + P1-dongle) of which 7 Daikin and 2 Viessmann

Additionally, 31 households agreed to participate in the pilot with the following assets:

- 1 electrical boiler (not sure yet whether this asset will participate in the asset steering)
- 7 Viessmann, 1 Daikin and 7 Nibe heatpumps
- 19 Huawei home batteries (not sure yet whether these assets will participate in the asset steering)

3.1.2. COFY Box

The Community Flexibility Box (COFYbox) is an open-source energy management system, running on a Raspberry Pi minicomputer. It uses Home Assistant, open source domotics software, to connect to different pieces of equipment and schedule automated behaviour in the home.

In the context of the Flexsys project, new developments to the COFYbox-platform are made in the form of the *Flexibility Stack*: a software architecture implemented within COFYbox that provides layered abstraction within the decision-making process.

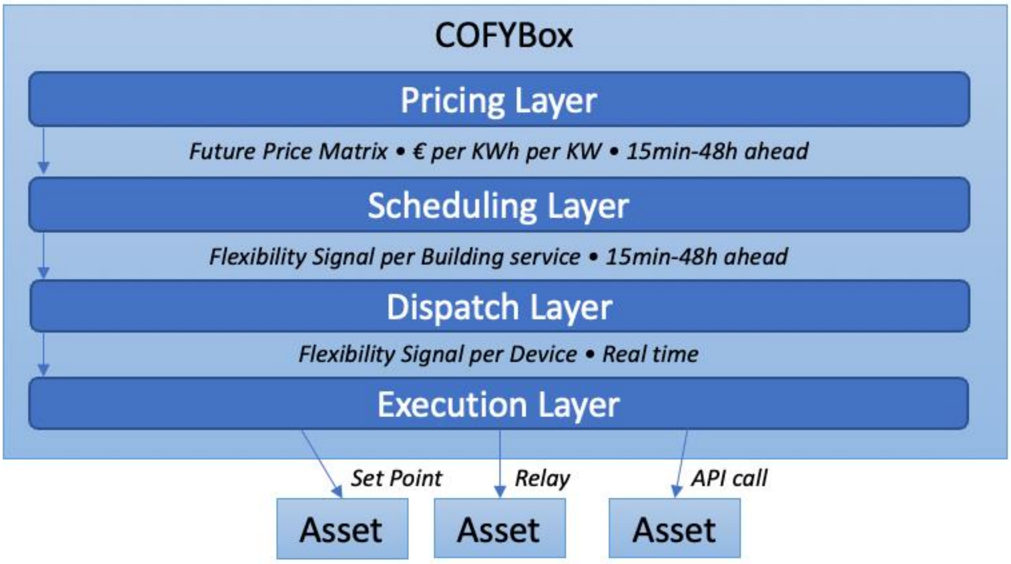

Figure 2: COFYbox Flexibility Stack based on 4 layers: Pricing, Scheduling, Dispatching and Execution.

Pricing Layer

The main incentive for flexibility is *price*: ideally, higher electricity prices signify an increased (forecasted) unavailability of renewable energy, congestion, or imbalance on the grid. However, there are multiple components that make up the final electricity price at the consumer's home: the day-ahead traded electricity, represented by a dynamic electricity tariff from the energy supplier; the amount of locally produced solar power, represented by a dynamic injection tariff that the energy supplier would pay when injected; dynamic distribution tariffs (capacity tariff); and any additional incentives an energy supplier or balance responsible party is willing to add or subtract from the total in order to incentivize balancing efforts.

The innovative approach of the *Pricing Layer* is combining all these pricing input into a single *future price matrix*, that condenses all this info into a single price per kWh per capacity, for every block of 15 minutes. This can be done for a forecast horizon of 24 to 48 hours.

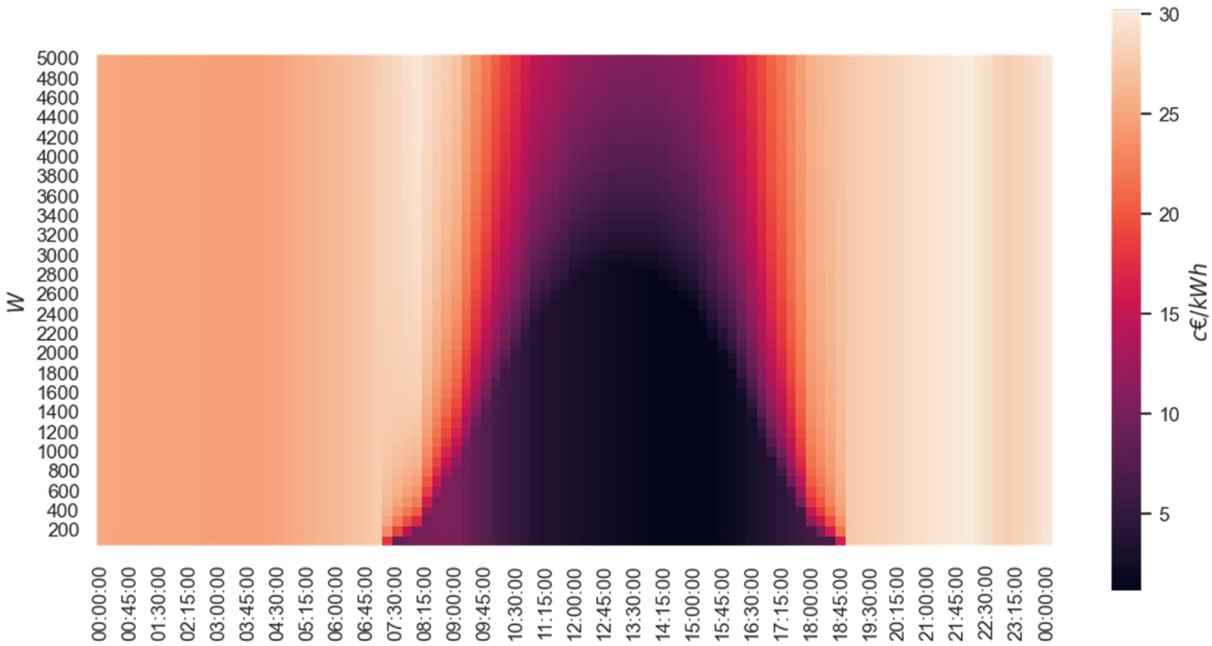

Figure 3: Future Price Matrix, combining a dynamic electricity tariff and PV-output.

Scheduling Layer

The *Scheduling Layer* considers the *energetic services* that are needed in any building (These are defined by ISO52000 Energy Performance of Buildings. Relevant examples are *Heating, Domestic Hot Water, Cooling, Personal Transport, Electrical Storage*) and assigns them one of five flexibility modes: Force Off (--), Advice Off (-), Normal (0), Advice On (+), and Force On (++).

--	-	0	+	++
Force Off	*Advice Off*	*Normal*	*Advice On*	*Force On*

Figure 4: The 5 flexibility modes used by the *Scheduling Layer*

The assignment of these modes is done by applying simple *rules*, that any homeowner or technical installer can interpret. E.g.: during the 4 cheapest hours of the day, *Heating* is *Advised On*; during the 4 most expensive hours of the day, *Heating* is *Advised Off*.

Dispatching Layer

The *Dispatching Layer* considers the actual appliances in the building, and links them to their respective *energetic service*. Next, it translates the given flexibility mode to a setting or set point that works specifically with that appliance.

--	-	0	+	++
Blocking	*Blocking*	*Normal clock*	*Advice 45˚*	*Forced 55˚*

Figure 5: Translation table of Flexibility Modes, for dispatch to a Heat Pump. Note that this heat pump has only 4 distinct settings, hence both *Advice Off* and *Force Off* are translated into a *blocking action*.

On top of translating flexibility modes to settings, the *Dispatching Layer* implements *user overrides* and *sanity checks*. These make sure that no comfort loss is suffered, or that no commands can be sent that would be damaging to the device (e.g. a blocking signal can only be sent to this Heat Pump for a maximum of 2 consecutive hours, and needs a minimum of 2 hours afterwards to recover)

Execution Layer

Finally, the *Execution Layer* contains the direct link to the device. E.g. it translates the dispatched signal into an action for a relay that is mounted on the Heat Pump.

Cloud Overrides

Both the Scheduling and Dispatching Layers contain functionalities to be overridden by an explicit signal coming from COFYcloud. This enables the aggregator to take specific actions that are not scheduled or bound by the rules set by the homeowner. The homeowner however always retains the final control, via an override button that can disable any external control.

3.1.3. COFYcloud

COFYcloud is the name of a group of cloud-based services:

- A portal for COFYbox users with visualization of measurements
- Repository for COFYbox updates and tools for remote support and debugging
- Online storage of COFYbox measurements
- Organisation of Communities, comprised of multiple COFYboxes

- Dispatching of prices, forecasts and flexibility signals to COFYboxes
- Aggregation of data per community
- API access of data for external platforms and aggregators

In the context of Market Coupling, extra work will be performed to develop ways for price incentives to be broadcasted to communities; explicit demand response signals to be scheduled and dispatched, and aggregated community data to be made available for the aggregator.

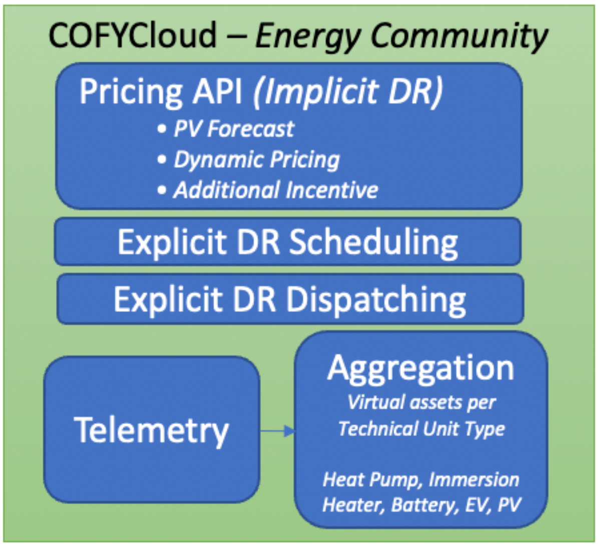

Figure 6: COFY-cloud

COFYcloud will aggregate distributed assets into a single virtual asset per technical unit type: a single virtual heat pump, immersion heater, battery, electric vehicle, and PV-plant. This architecture will allow Next Kraftwerke's Virtual Power Plant to interface with the community, as if all these assets were one big asset.

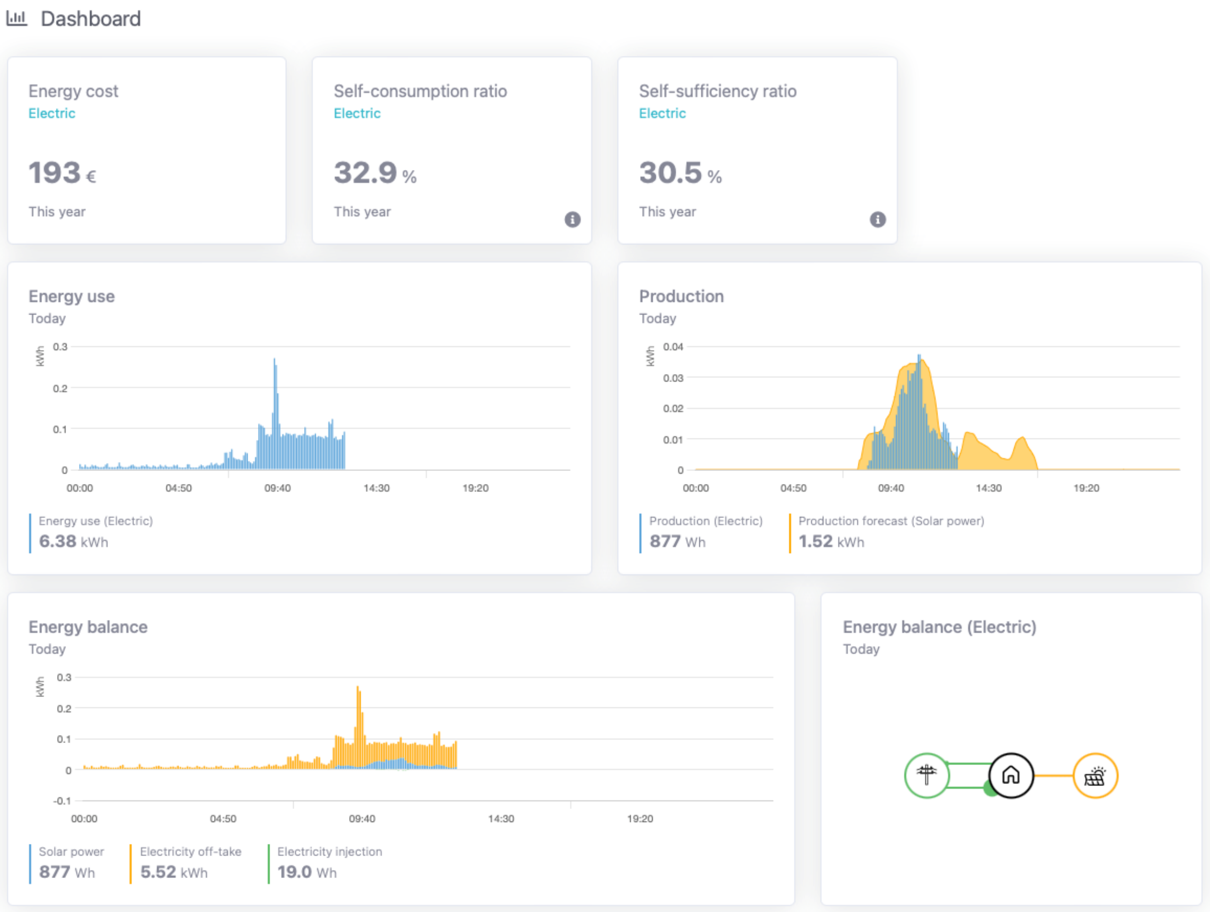

Figure 7: Community dashboard

3.1.4. Next's Virtual Power Plant technology

What is a Virtual Power Plant (VPP)? (Figure 8)

"A Virtual Power Plant is a pooled set of decentralized units in a power network. Virtual Power Plants are operated by a common, centralized control system. The networked units can be power producers (such as biogas, wind, solar, CHP, or hydro power plants), power consumers, power storage units, and power-to-X plants (power-to-gas, power-to-heat). The Virtual Power Plant's purpose is to collectively forecast, dispatch, and trade the power and the flexibility of the aggregated assets. Any decentralized unit that produces, consumes, or stores electricity for the power exchanges can be part of a Virtual Power Plant. The cluster of individual assets is operated by a central control system. In addition to operating each individual asset in the Virtual Power Plant, the system uses a special algorithm to adjust to grid conditions and control reserve commands from transmission system operators – just like larger, conventional power plant (hence its name...). When it comes to trading electricity, the Virtual Power Plant can react quickly and efficiently to price signals from the power exchanges and adjust operations accordingly." Next-Kraftwerke

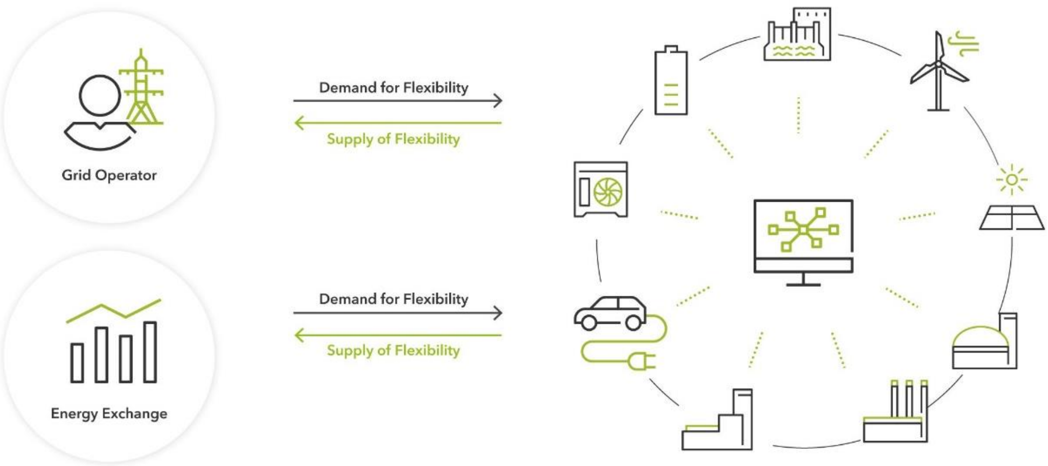

Figure 8: Virtual Power Plant, source: www.next-kraftwerke.be

For the Flexsys pilot, the VPP connection is set up as follows:
In the Next Kraftwerke data center in Cologne, the control system of the VPP runs and will be physically connected to The Next Box (Figure 9).

The central control system can be considered as the brain of Next-Kraftwerke's VPP. It is a complex IT system designed with high security, performance and availability requirements to communicate with Elia's control center on the one hand and with the individual flexible assets on the other hand. The central control system translates setpoints from Elia, which indicate the total level of power requested, into setpoints for the individual assets. As such, the control system constantly checks the asset's status and availabilities to decide how much flexibility each asset can and should provide to meet Elia's request.

The Next Box is the device that links the central control system and the virtual assets in the COFY cloud. Usually, the Next Box is located close by the asset to be steered, so that a wired serial connection can be made without depending on local or public internet networks. However, as the residential assets will be steered as one aggregated group in the pilot, this approach is not possible. Instead, the Next Box will be installed at the data center of Next Kraftwerke in Cologne and a dedicated internet connection over an open VPN tunnel will be established between the Next Box and the COFY cloud. The protocol that will be used is Modbus TCP/IP.

The central control system and the Next Box will be connected via physical cables. They exchange asset data and set points in real-time. The setpoints indicate the level of power requested from a certain asset or a group of virtual assets to restore the grid frequency or to respond to price signals.

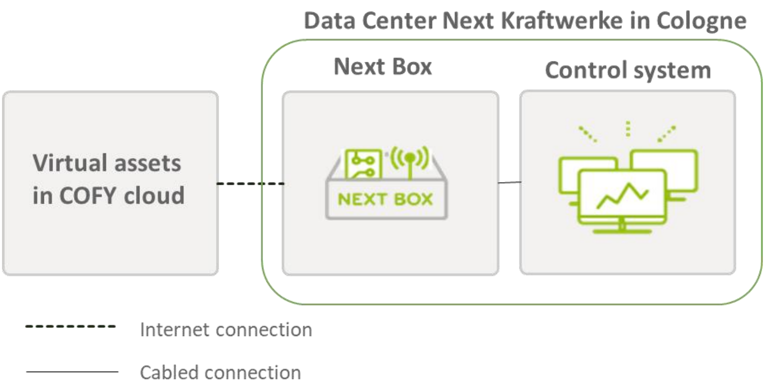

Figure 9: Technical set-up of the Next VPP in connection to the virtual assets in the COFY cloud.

3.2. Component interactions

3.2.1. Interactions between the household assets and the COFY box

3.2.1.1. Requirements for the household

The installation procedure for COFYbox is documented on docs.cofybox.io. For the scenarios to be run in this project, the minimal requirements are:

- Measurement of the grid energy and power (preferably via P1 dongle, optionally via current clamps)
- Measurement of PV-production requires a *Sunspec* equipped PV-inverter connected to the local network.
- Measurement of battery state of charge, charging and discharging power and energy
- Per flexible equipment:
    - Must be controllable (either networked, via COFYcookie relay, or smart plug)
    - Is preferably submetered
- Temperature measurements (of the home, buffer temperature) are preferred. This enables more accurate sanity checks and minimizes comfort loss.

3.2.1.2. Requirements for the energy community

COFYboxes upload a set of sensors on a 5-minute interval:

- Grid energy and power: offtake and injection
- Solar PV production
- Battery state of charge in kWh, charge and discharge energy and power
- Submetering (energy and power) of building services (heating, domestic hot water, electric vehicle) *

* Not every subsystem has these measurements

Secondly, every building services' schedule and active dispatch state is logged (see 3.1.2 on the COFYboxes' scheduling and dispatching layer). Current power consumption data, combined with these schedules, result in a (probable) available flexibility and future availability per building service.

3.2.2. Interactions between the COFY cloud and the Next Box

Depending on the flexibility strategy (i.e. implicit or explicit) different technical requirements concerning the communication between COFY cloud and Next Box are in place.

Implicit flexibility

The provision of implicit flexibility requires the availability of day-ahead prices which households could react on. Intraday and imbalance steering are also included as part of this strategy, as well as solar forecasting for households with PV systems.

A dynamic day-ahead tariff is made available by Ecopower via API. This tariff is based on the publicly available day-ahead prices (EPEX).

Next Kraftwerke will not be able to provide the imbalance or intraday prices directly to the COFYcloud, as the internal systems are not adjusted for this type of data exchange. Imbalance prices, however, can be directly imported from the Elia database via an API. These prices can be found on the Elia database: https://opendata.elia.be/pages/home/.

Explicit flexibility

The provision of explicit flexibility for aFRR and mFRR requires a real-time, bidirectional data exchange between the Next Box and the COFYcloud. In order to participate on the market, the Next Box needs to receive the following signals:

- Availability (0/1) - default 0
  This signal specifies whether the (virtual) asset is available for remote activation. All states, which impede the remote activation must be integrated in the availability signal (e.g. outages or manual operation)
- Operation (0/1) - default 0
  This signal is used for trouble shooting, as it indicates whether the (virtual) asset is actively producing or consuming power – irrespective of its availability for remote control.
- Active power (kW)
  This signal constitutes the generated power (AC-side). This signal is regarded from the grid perspective, meaning that injection is transmitted as a positive value and consumption as a negative value.

The Nex Box receives these signals from the COFYcloud, where they are synthesized based on data coming from multiple assets. Therefore:

- Availability will be set to 1 if the Community is available for activation and if 1 or more individual assets are available for activation.
- Operation will be set to 1, if 1 or more assets are actively producing or consuming power. It should be noted that it will not be possible to know this for all assets, because manufacturers do not always allow for such measurements.
  However, the active flexibility signal for each service within the COFYbox is logged and can be aggregated.
- Active power is the net sum of all grid measurements.

At the same time, the COFY cloud needs to be able to receive and process the following signals from the Next Box:

- Activation (0/1) - default 0
  This signal activates the virtual asset for remote steering. If the activation is active (1), the plant runs automatically on the setpoint given by the Next Box. The active activation signal requires an availability signal of 0.
- Setpoint (kW)
  This signal sets the required operating point of the (virtual) assets, which is needed to restore the grid balance. It is only valid when the activation signal is active. The setpoint is considered from the AC side, analogous to the active power signal. Positive setpoints represent injection into the grid and negative setpoints represent offtake from the grid.

COFYcloud will map the Setpoint to the 5 flexibility modes implemented on the COFYbox (see 3.1.2), and dispatch that vector to the entire fleet. Because the assets used in the project often do not have a way to accept an exact setpoint in kW, this method may yield inaccurate results. It is expected however that the accuracy will improve over time due to better and more exact API's, larger fleets, and more precise calibration of the algorithm.

Additionally, a probabilistic ramp rate can be used if a more granular response is required. This is achieved by sending a switch probability along with the control vector. Each COFYbox then decides whether to follow the vector, by virtually tossing a random number between 0 and 1 and evaluating it with the switch probability.

3.2.3. Interactions between the Next Box and the market

This interaction is already set up by Next Kraftwerke as part it is part of their core business and activities. This interaction includes a leased line with Elia for the provision of ancillary services.