UNIVERSITAT POLITÈCNICA DE VALÈNCIA

School of Industrial Engineering

Design, implementation and validation of a methodology for the aggregation of demand flexibility in the industrial segment based on Open Automated Demand Response (OpenADR): Application to a group of medium-sized industries located in Spain with an aggregated consumption of 120 GWh/year

Master's Thesis

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"To my supervisors
To my family
To my close friends

Thank you for your support!"

Dennis Duyck

Valencia, June 2024

RESUMEN

El objetivo de este Trabajo Fin de Máster es el desarrollo de una metodología que permita la agregación de cargas individuales para ofrecer su flexibilidad conjunta a un tercero interesado. La arquitectura del sistema propuesto se basará en la tecnología denominada Open Automated Demand Response (OpenADR), desarrollada por primera vez por el Laurence Berkeley National Laboratory (LBNL) en California, y aplicada con éxito a la gestión de la respuesta a la demanda en diferentes tipos de instalaciones (especialmente residenciales y comerciales). Además, se realizará un análisis comparativo con protocolos o sistemas alternativos para agregadores con el fin de justificar la conveniencia de OpenADR para la aplicación propuesta.

La metodología se aplicará a un caso real para su validación, consistente en un conjunto de industrias de tamaño medio pertenecientes al sector de la producción alimentaria. Están ubicadas en diferentes partes de España y serán agregadas con el fin de ofrecer su flexibilidad al Operador del Sistema de Transporte (TSO) para servicios de balance y reserva. Este caso real será evaluado desde el punto de vista técnico, económico y medioambiental, valorando el impacto de la aplicación de esta metodología para los consumidores como para el Operador del Sistema.

Palabras clave: OpenADR, respuesta de la demanda, flexibilidad, desplazamiento de carga, agregador, servicios complementarios, industria

ABSTRACT

The aim of this Final Thesis of Master is the development of a methodology to allow the aggregation of individual loads in order to offer their joint flexibility to a third stakeholder party. The architecture of the proposed system will be based on the technology called Open Automated Demand Response (OpenADR), first developed by the Laurence Berkeley National Laboratory (LBNL) in California, and successfully applied to demand response management in different types of facilities (especially residential and commercial). Furthermore, a comparative analysis with alternative protocols or systems for aggregators will be performed in order to justify the convenience of OpenADR for the proposed application.

The methodology will be applied to a real case for validation purposes, consisting of a set of medium-sized industries which belong to the food production sector. They are located in different parts of Spain and will be aggregated in order to offer their flexibility to the Transmission System Operator (TSO) for balancing and reserve services. This real case will be evaluated from the technical, economic and environmental point of view, assessing the impact of the application of this methodology on both sides (consumers and TSO).

Keywords: OpenADR, demand response, flexibility, load shifting, aggregator, ancillary services, industry

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1 Introduction

1.1 Background

Energy is key to people's daily lives. The energy mix will be more and more diverse and variable. According to Eurostat, the energy mix for the European Union in 2021 was for crude oil and petroleum products 34%, natural gas 23%, renewable energy 17%, nuclear energy 13% and solid fossil fuels 12%. Figure 1 visualises these statistics. By 2050, the statistics will look different because petroleum products, natural gasses and solid fossil fuels are going to run out. Also, due the climate change, the use of fossil fuels will change. Utilizing advanced technologies is crucial for establishing a diverse energy system capable of achieving a varied energy mix. [1]

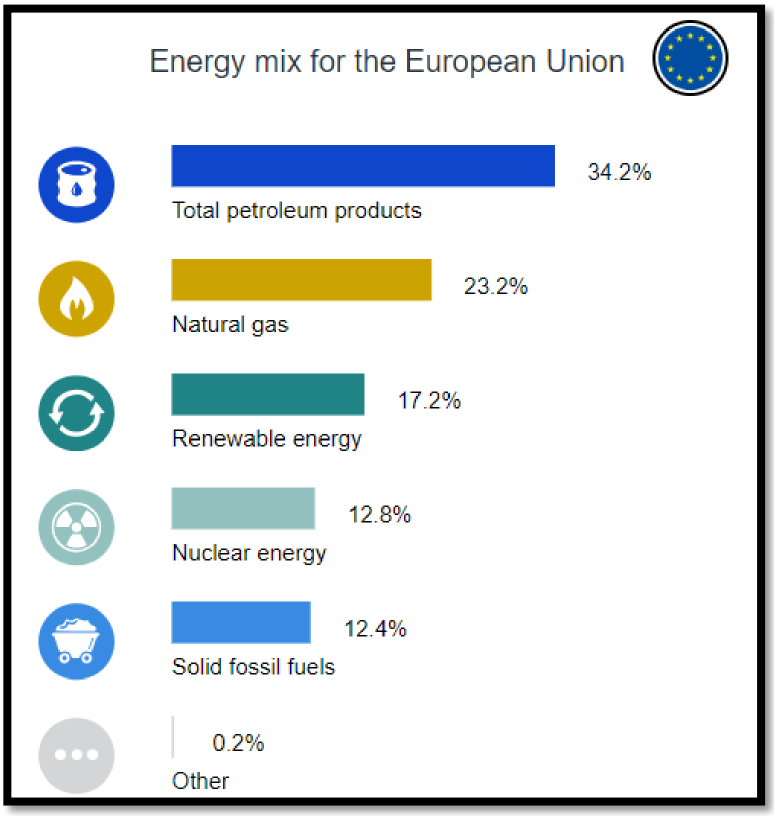

Figure 1: Energy mix in the EU in 2021. Source: Eurostat [1]

According to the International Energy Agency (IEA), technologies like demand response can help to achieving the Net Zero Emissions by 2050 Scenario (NZE Scenario). NZE Scenario is a normative scenario that shows a pathway for the global energy sector to achieve net zero CO_2 emissions by 2050. The widespread use of solar PV and wind adds complexity due to their variable output based on weather and time of day. The electrification of various sectors will lead to a significant rise in electricity demand. Technologies such as demand response can help manage this surge, minimizing the necessity for expensive upgrades to transmission and distribution infrastructure. [2], [3]

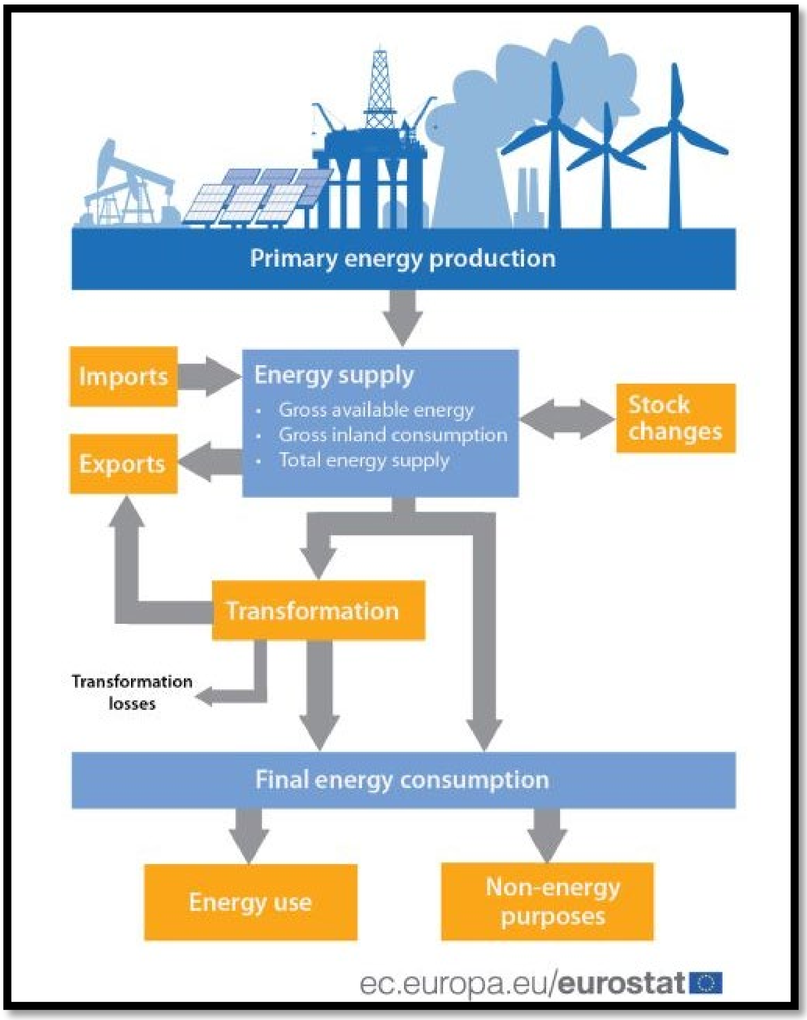

Figure 2: The different steps in the energy flow. Source: Eurostat [4]

The processes involved in producing energy and consuming energy are very complex. Figure 2 visualise the different steps in the energy flow. Primary energy production includes fossil fuels, nuclear energy, and renewable sources of energy like solar, wind and water. If a country's primary energy production falls short of its total energy requirements, it must acquire the remaining energy from external sources or its reserves. [4]

Energy products can be directly consumed, such as natural gas for heating. Alternatively, they can undergo a transformation process to create a different energy product, like natural gas converted into electricity at power plants. After these transformations, the transformed product can be either exported to other countries or consumed for energy use or non-energy purposes. It's important to remember that there are energy losses while transforming due the second Law of Thermodynamics as energy conversions are not perfect. This implies that each time energy changes from one form to another, a portion becomes unusable, such as heat dissipating into the environment. [4], [5]

Electricity matters to all of us. For getting a better picture about the electricity production and the share of sustainable energy sources, these paragraph gives some extra statistics from Eurostat. Figure 3 visualise these statistics. Around 23% of the final energy that was consumed is electricity and it comes from different sources. In 2021 in the European Union (EU), renewable energy was the leading source in electricity production (37%), ahead of fossil fuels (36,5%) and nuclear power plants (25%). It highlights the growing importance of clean energy in the European Union's energy mix. Wind turbines (13%) were among renewable sources the highest share of electricity, followed by hydropower plants (12%), solar power (6%) and biofuels (5%). [1]

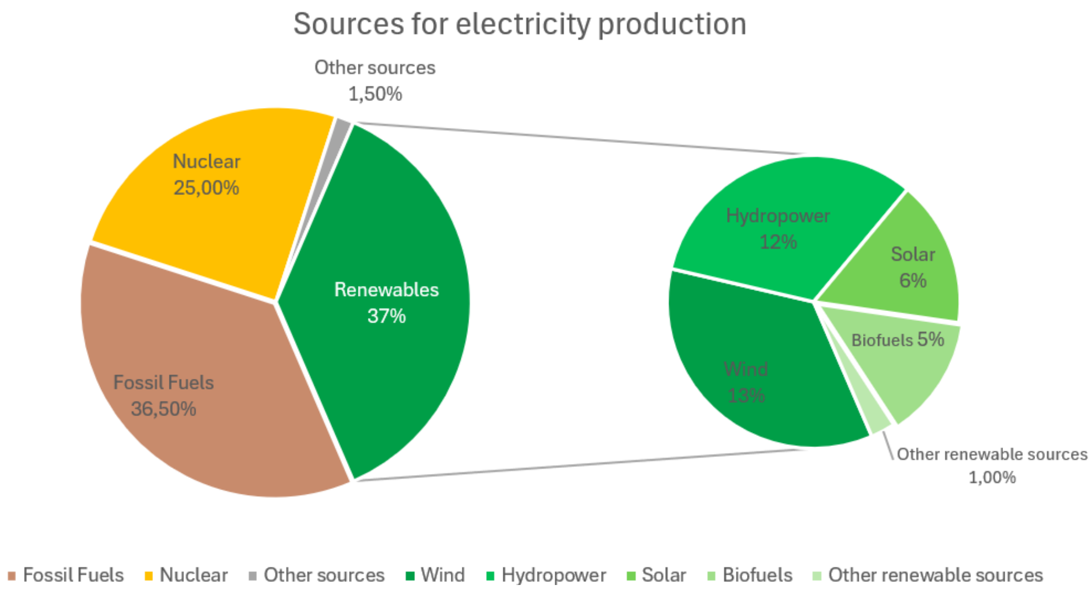

Figure 3: Sources for electricity production in 2021 in the European Union. Source: Own elaboration based on Eurostat [1]

Another way to visualise the energy products in an illustrative and intuitive way is a Sankey diagram. Figure 4 illustrates a Sankey diagram of the energy balances for the European Union (27 countries) in 2021. The energy flows (in different colours) represent the different energy products. See also the legend for the meaning of each colour. The width of each stream in the flow represents the amount of energy (fuel). The largest stake is oil and petroleum products, followed by gas. It's remarkable that a large part of the energy is transformed, 14 340 667 GWh of the available energy is transformed from all sources 21 887 698 GWh. This represents a 65,52 % share. The countries of the European Union also import a significant amount of energy products, especially oil and gas. [4], [6]

Overall, the Sankey diagram shows that the energy mix is still leaded by fossil products. Renewables plays a smaller role, but for the future it is growing in importance. These energy transition towards renewable energy sources like wind and solar is crucial for preventing climate change. Renewables are a variable source of energy because it is depending on the weather. Open Automated Demand Response (OpenADR) integrates these decentralized renewable grid systems for flexibility and balancing the global grid. OpenADR is a communication protocol enabling (automated) demand response, allowing utilities and energy aggregators to communicate with customer devices for adjusting energy use during peak periods or grid emergencies. See also section 2.5 for detailed information about OpenADR. [7]

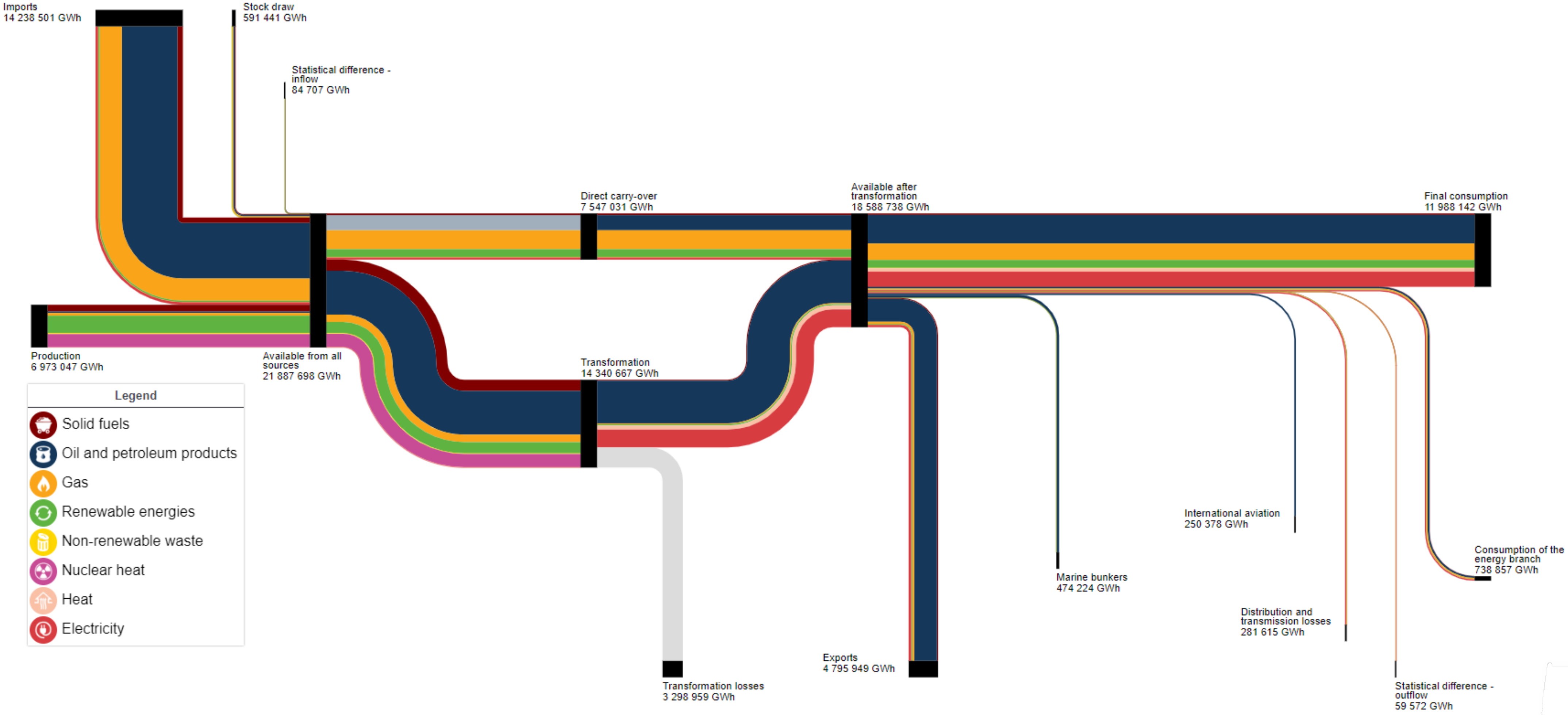

Figure 4: Sankey diagram of the energy balances for the European Union (27 countries) in 2021. Source: Eurostat [6]

1.1.1 Reducing greenhouse gas emissions

Rising temperatures, extreme weather events, and sea level rise due to climate change all undermine efforts towards sustainable development.

The scientific community agrees that man-made greenhouse gas (GHG) emissions are the dominant cause of the Earth's average temperature increases over the past 250 years. Primarily, man-made GHG emissions are a by-product from burning of fuels in power plants, houses or vehicles. But agriculture and waste decaying in landfills are also sources of GHG emissions. OpenADR can combating climate change by facilitating a reduction in greenhouse gas emissions, particularly those associated with the power sector. [1], [8]

- **Peak shaving and load balancing**
  OpenADR empowers utilities to implement demand response programs that incentivize consumers to adjust their electricity consumption during peak hours. This reduces the strain on power plants, allowing them to operate more efficiently and minimizing the need for ramping up less-environmentally friendly power plants. [9], [10]
- **Smart grid optimization**
  OpenADR allows two-way communication between utilities and consumers. It also saves important information about the price per kilowatt-hour, energy loads, etc. This facilitates better forecasting of electricity demand, enabling utilities to optimize power generation from cleaner sources and reduce reliance on fossil fuels. [9]
- **Better integration of renewables**
  As renewable sources are variable and decentralised, OpenADR enables the possibility to real-time adjustments. It can mitigate the potential for grid instability when renewable power generation are fluctuating.[9]

In conclusion, OpenADR stands as a valuable tool in the fight against global warming by peak shaving, load balancing, optimising the smart grid and facilitating the integration of decentralised renewable energy sources. It is important to keep in mind that the impact of peak reduction is not always proportional to lower gas emissions. For example, Germany relies on photovoltaic sources for peak electricity generation, but is dependent on CO_2-emitting lignite plants for nighttime baseload. Simply reducing peak demand might not align with reducing greenhouse gas emissions in such a scenario. Therefore, the strategies to follow in each country will depend on the (future) generation mix of that country. [11], [12]

1.2 Objectives

General objective

The main objective of this thesis is to design, implement, and validate a methodology for aggregating demand flexibility in the industrial sector, specifically focusing on medium-sized industries in Spain with an aggregated consumption of food factories. This methodology will be based on the Open Automated Demand Response (OpenADR) technology and it will be evaluated from technical, economic, and environmental perspectives.

Specific objectives

- Provide a comprehensive technical description of demand response aggregation and OpenADR implementation in the industrial sector based on existing literature and practices.
- Compare other protocols or systems related to demand response with OpenADR
- Develop a general design architecture for aggregating demand flexibility using OpenADR.
- Apply the general design architecture for aggregating demand flexibility using OpenADR with real data from food factories in Spain.
- Validate the design architecture through testing and simulation with the OpenADR tools from GRIDlink Technologies.
- Calculating and validating the impact from the demand response on energy consumption, cost savings, and environmental benefits.
- Analyse the technical, economic, and environmental implications of the proposed methodology.
- Provide recommendations for the wider adoption of demand response aggregation with OpenADR in the industrial sector, contributing to a more sustainable energy system.
- Provide and identify potential challenges and opportunities for further improvement.

1.3 Scope

The scope of this thesis is limited to the design, implementation, and validation of a methodology for aggregating demand flexibility in the industrial sector using OpenADR. The focus is on medium-sized food industries located in Spain. The OpenADR platforms used in this thesis are extensive, but they are not fully studied or described. The study will primarily consider the technical, economic, and environmental evaluation of the proposed methodology, excluding detailed analysis of other factors such as political implications.

The thesis will not delve into the development of the OpenADR protocols or standards but will focus on utilizing existing OpenADR specifications and tools. The evaluation of flexibility will be used on the procedure developed during the Demand Response in

Industrial Production (DRIP) project and it will be limited to a specific set of industries. [13] So, the obtained results will be applicable to the considered industrial segment of food industrial factories. The OpenADR platform used is very specific which may make their use in other scenarios incompatible. The recommendations provided for wider adoption will be based on the findings of this study and may require further research and adaptation for different contexts and regions.

1.4 Motivation

In the evolving landscape of energy systems, the integration of advanced technologies is necessary to achieving sustainable and efficient energy management. The energy production will be more decentralized and dynamic due the higher use of renewable energy production. This thesis delves into the design and implementation of a methodology tailored for the aggregation of individual loads. This within the context of medium-sized industry from food factories in Spain. OpenADR emerges as a possible solution for enabling seamless communication and coordination between utilities and end-users. Demand response, as a key component of smart grid technology, plays a fundamental role in balancing energy supply. Other important key components from OpenADR will be explained later in this document.

1.5 Organisation of the document

Chapter 2 describes the state of the art in aggregation. In this section, there is also an introduction to OpenADR, a comparison with other protocols or systems for demand response and why choosing OpenADR. Additionally, the relevant technical terms for OpenADR are explained. In chapter 2.5 a methodology is proposed for the aggregation in demand response with OpenADR. The explanation of the important key functions of the OpenADR platforms can here be found. Requirements and how to evaluate the results are also described in this chapter. In chapter 4 the methodology is applied by a practical case study with data from food factories. Also, some results from the OpenADR tools are given. Finally, some conclusions are drawn in chapter 5.

2 State of the art on aggregation and automated demand response

Aggregators can play a critical role in balancing supply and demand in real time. Demand response is becoming more and more important with the growth of renewable energy. Aggregators are entities within electricity systems that can influence a number of grid-connected units through a suitable communication interface. These technological advancements in the field of energy management have become more and more desired because the electric grid is undergoing a transformation. The transformation of the electric grid needs a smart information exchange platform. One such state-of-the-art information and exchange technology platform is the Open Automated Demand Response (OpenADR) protocol. A demand response happens when a utility, aggregator or grid operator enables electricity customers to change their power consumption through financial or other incentives. This chapter dives into the aggregator role and the OpenADR protocol. There will be also a comparison between OpenADR and other protocols or systems applicable to aggregators. After this the reason behind choosing OpenADR for the aggregator will be explained. [14], [15]

2.1 The aggregator role

Electric load aggregation is a strategy employed by different stakeholders to establish an alliance with the aim of securing energy rates that are more affordable than the current market rates. This process needs a significant amount of data to comprehend the needs and ensure efficient grid functioning. An aggregator refers to a collective of agents in a power or any other energy system to act as a single entity. In the case of the electricity approach, agents could be consumers, producers, prosumers or any combination of these. The aggregator can both participate in power system markets (including wholesale and retail) and selling services to the operator. [16], [17], [18]

Aggregation can benefit both upstream and downstream participants in the energy market. For downstream participants (industrial, commercial, or residential users), aggregators help boost revenue and cut costs. These downstream participants are only users with generation and storage capabilities or those able to provide demand response. For upstream players like Transmission System Operators, large electricity generators or Distribution System Operators, aggregators assist in optimizing portfolios, as well as managing system balancing and congestion. [16], [17], [19]

An aggregator has the capability to manage numerous distributed energy resources (DERs). These DERs are typically small to medium-sized resources and are directly linked to the distribution grid. Usually, they are connected at lower voltages levels than conventional centralized resources. They play a significant role in supplying electricity services. In a smart grid, one of the main providers of electricity services are DERs. The components of DERs encompass a wide range of technologies including distributed power generation, energy storage systems like compact batteries, and controllable loads. Examples of controllable loads include electric vehicles, heat pumps, and demand response mechanisms. Figure 5 shows the most important kinds of DERs.[16], [17], [18], [19]

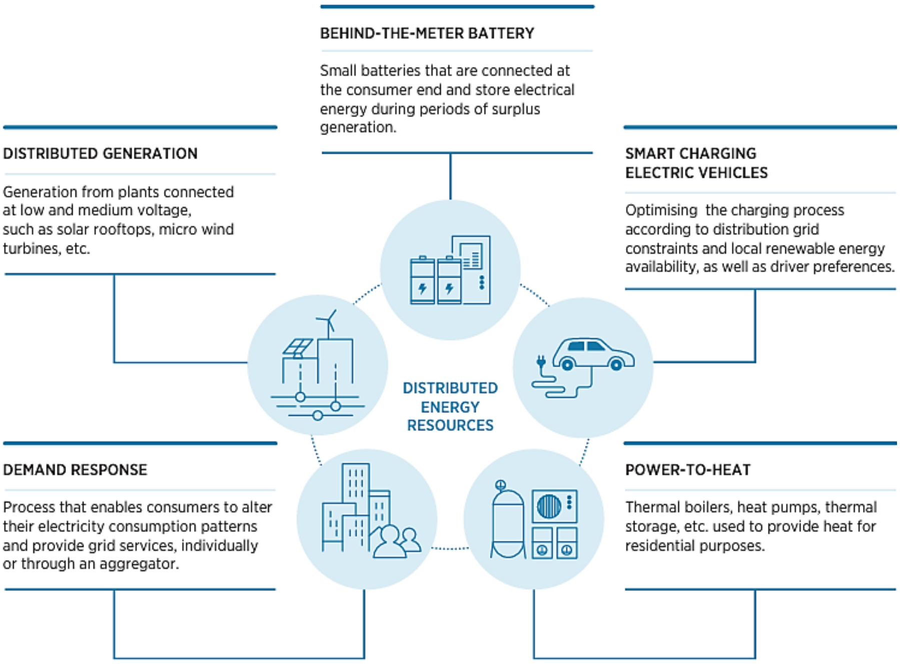

Figure 5: Different kinds of distributed energy resources (DERs). Source: IRENA [16]

So, DERs include a wide range of technologies. This variety leads to significant differences in their technical and economic characteristics. Even within the same category of DERs (like batteries), performance and cost can vary substantially. For instance, comparing a lead-acid battery with a lithium-ion battery reveals substantial differences. If a comparison is to be made, further analysis must be undertaken. This is out of the scope of this thesis. [18], [20]

In another context, an aggregator refers to a corporation that operates a Virtual Power Plant (VPP). A VPP is essentially a collection of DERs with the aim of enabling small energy sources to provide services to the grid. VPP operators functions like a conventional power plant, with specific attributes such as minimum and maximum capacity, as well as ramp-up and ramp-down rates. This integration allows VPPs to engage in electricity markets and provide ancillary services. A central information technology (IT) system controls the VPP. The IT system is also able to connect different forecasts to optimize the operation. Typical forecasts are demand forecast, wholesale electricity market prices and the supply forecast. [16], [20]

Operational optimization relies on analysing historical and forecasted data regarding energy demand, power generation, and market prices. Figure 6 provides an overview of how an aggregator operates the distributed energy resource (DER). The black dashes lines show the power flow. The blue solid line is the information flow where OpenADR or another protocol can be used. A central IT control system sends an optimised schedule to the dispatchable distributed energy resources. Sometimes is the central IT control system referred as a decentralised energy management system (DEMS). [16]

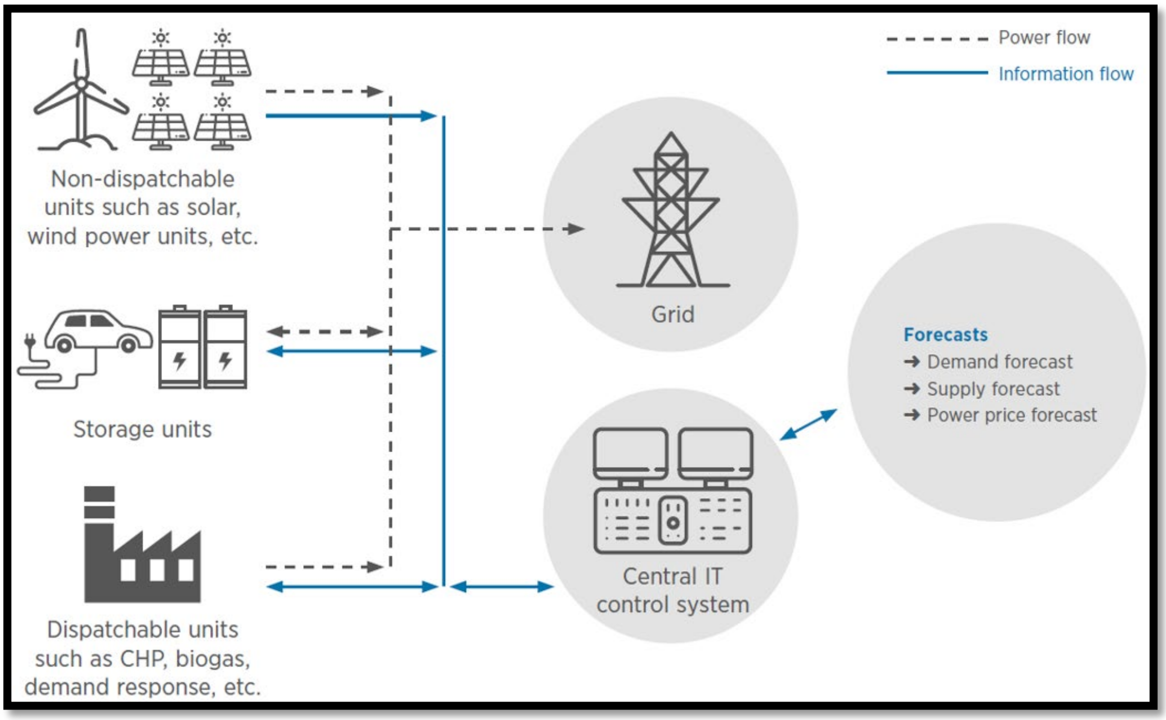

Figure 6: Overview of an aggregator. Source: IRENA [16]

An aggregator can play a crucial role in better inclusion of renewable energy resources by offering flexibility services to the grid from both the demand and supply sides (Figure 7). On the supply side, flexibility is ensured by optimizing power production from adaptable resources like combined heat and power (CHP) plants, genset units, and others, along with the utilization of energy storage systems. While large-scale wind and solar photovoltaic farms are centralised nowadays, is distributed generation growing. When there is an excess of renewable energy production, one promising strategy is to electrify end-use sectors. This strategy serves to maintaining the value of renewable energy, minimizing curtailment, and most importantly, accelerating decarbonization efforts. On the demand side is achieved by uniting demand-response resources or energy storage systems to meet the grid's needs. The increasing effort of supplied energy resources turns the consumer into active participants within the power market, facilitating enhanced demand-side management. [16], [20], [21]

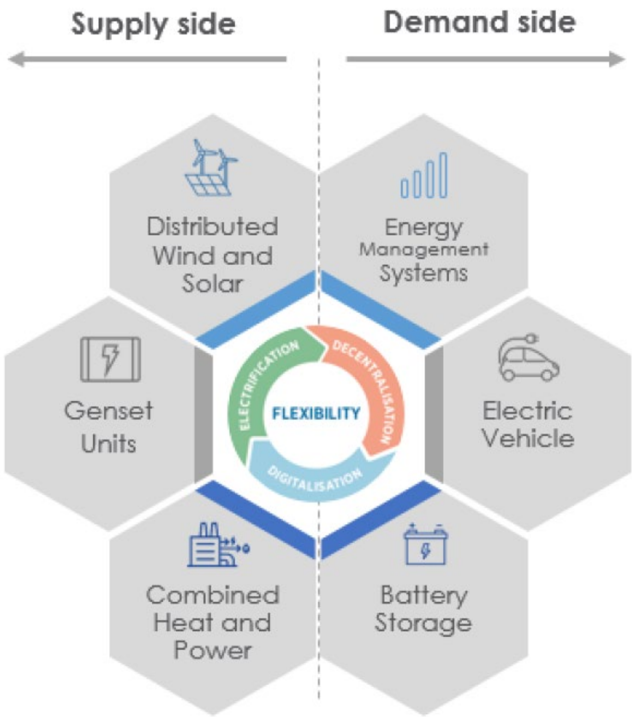

Figure 7: Supply side and demand side. Source: IRENA [16]

Large-scale data collection and sharing are essential for VPP operations, which aggregate demand-side loads. This necessitates robust privacy and security protocols to safeguard data throughout its lifecycle. While the importance of data privacy regulations is widely acknowledged, there is ambiguity regarding data access permissions for different actors. These access schemes may also vary between VPP systems. From an aggregator's perspective, access to end-user consumption data and behavioural patterns is critical for optimizing forecasting and scheduling algorithms. Therefore, aggregators must prioritize robust cybersecurity measures (including secure measurement, communication, and control equipment) to gain and maintain customer trust. This fosters a secure environment that encourages end-user participation in the market. The scope of this work excludes a deep dive into cybersecurity of aggregators. [16], [20]

Aggregators can create a sizeable capacity to participate in wholesale power markets by bundling DERs and creating VPPs. By effectively managing a diverse portfolio of DERs, aggregators can provide a range of services to the grid like frequency regulation, operating reserve capacity, etc. Here are the key benefits aggregators can provide: [16], [21]

- **Grid services**:
  Aggregators can adjust loads (load shifting), provide backup power (balancing services), and offer local grid flexibility (if there is a regional market available). They can smooth out fluctuations caused by solar and wind power variations. For example, aggregators counteract the “ramps” that occur when solar power decreases in the evening or due to fluctuations in other variable generation outputs. [16], [18], [19], [21]

- **Reduced power costs**
  Aggregators can lower the system's marginal cost by reducing the need for expensive peak power plants. By adjusting loads during peak times, they can avoid the high costs of firing up additional fossil fuel plants. [16], [18], [19], [21]
- **Optimising investment in power system infrastructure**
  Aggregators can bundle and control existing DERs to provide reserve capacity, reducing the need to invest in additional peak generation infrastructure. This leads to a more efficient utilization of current energy resources. [16], [18], [19], [21]

Establishing an aggregator requires specific capabilities:

- **Regulatory framework**
  A liberalised wholesale power market without price caps is crucial. The main motivations for creating an aggregator are given by the price disparities between peak and off-peak periods in wholesale markets. Or by signals from transmission system operators to bring control reserve or other ancillary services. The regulatory framework should allow aggregators to participate in wholesale and ancillary service markets. [16], [18], [19], [21]
- **Realtime communication between VPP operators and the connected DERs is needed.**
  VPP operators require real-time data from connected DERs. This requires a robust communication infrastructure. This includes broadband connectivity, smart meters, network remote controls etc. Such infrastructure supports efficient network management and improves demand forecasting accuracy. OpenADR can play an important role in the communication exchange. [16], [18], [19], [21]
- **Better generation forecasting**
  To predict renewable energy output and system load, advanced forecasting tools are essential. These tools help determine the optimal dispatch schedule for DERs, allowing aggregators to better manage variations in renewable generation and demand. [16], [18], [19], [21]

Figure 8 gives a good summarise of the implementation requirements for aggregators. In conclusion, electric load aggregation offers a highly effective strategy for reducing costs and minimizing risks in today’s power markets. However, it is essential to understand that prices within an aggregated group can differ based on factors like individual load factors, service costs, and supply goals. Even with slight price differences, electric load aggregation remains a strong method for companies with diverse load profiles and capacities to achieve significant cost savings. [16], [21]

TECHNICAL REQUIREMENTS	**Hardware:** • Controllable load and supply assets such as energy storage, electric vehicles and distributed generation • Smart meters (to provide real-time power consumption and production), home gateways (energy boxes) and smart appliances for energy management, to enable VPP operation
	Software: • Aggregation software, algorithm to calculate the optimal operation of each unit • Real-time communication between the aggregator and the hardware system • Advanced demand and supply forecasting models/platforms for optimised scheduling of dispatchable distributed energy resources
	Communication protocols: • Common interoperable protocol for co-ordination among system operators, network operators and prosumers
REGULATORY REQUIREMENTS	**Wholesale market:** • Participation of aggregators should be allowed in electricity wholesale markets and ancillary service markets • Introduce regulations allowing decentralised sources to provide services to the central/local grids • Clear price signals to guide the aggregators' operations • Regulations to mandate implementation of smart meters and smart grid infrastructure
	Distribution: • Establishment of local markets for DSOs to procure services to avoid grid congestion and ensure grid stability • Data collection, management and sharing rules for DSOs to ensure consumer privacy
	Retail market: • Regulators should define a standardised methodology for computing dynamic prices that can be adopted by retailers. • Functioning retail markets could provide innovative products and pricing models for various customer needs. For example, in Finland innovative products are being introduced, and customers can opt to choose the product and pricing method best suited to their needs (such as hourly dynamic pricing, retailers buying excess solar photovoltaic generation as a marketbased solution, ToU tariffs, etc.). • Regulation should set clear roles and responsibilities for market parties. Long-term foreseeable regulation is needed. • Liberalised markets, as opposed to regulated markets, could facilitate the market entry
	System operation: • Defining rules for co-ordination between distribution and transmission system operators
STAKEHOLDER ROLES AND RESPONSIBILITIES	**Aggregators:** • Provide grid-related services to DSOs, if a market is established • Information exchange with DSOs related to capacity, location, type of DERs
	Distribution system operators: • Ensure a level-playing field for all flexibility providers • Procure market-based flexibility services from aggregators • Securely share consumer and grid-related data with third parties as per applicable data privacy and sharing norms • Better forecasts for DER services based on past data or historical performance and weather forecasts

Figure 8: Implementation requirements for aggregators – checklist. Source: IRENA [16]

2.1.1 Evolution and examples of aggregators in Europe

In this section some examples of aggregators in Europe are given. The level of development of aggregators in the different European countries will also be described. Figure 9 shows the evolution of DR development in Europe from 2015 to 2017, used from reports of Smart Energy Demand Coalition (SEDC). The paper reviews the regulatory structures of 18 European countries. The legend for the map uses colours to represent the different stages of development of DR from green for commercially active to red for closed. [22], [23]

Once this initial analysis was completed, each Member State was given an overall grade according to the general status of Demand Response in the overall electricity market. This final grade consists of the total sum of the results in the following four criteria:

1 Demand-side resources access to the markets
2 Different service providers access to the markets
3 Product or program requirements
4 Measurement and verification, payments and penalties

A detailed analysis of these four criteria can be found within SEDC report. [23] It is important to note that the grading is relative to other markets, and even a green indication can mean that further improvements are still possible. A summary of this report is provided in the following paragraphs. Remark that these conclusions refer to the period 2015-2017. Yet these conclusions can still provide interesting insights. [22], [23]

From 2015 to 2017, the research shows that there has been an overall increase of interest in enabling Demand Response in almost of all the countries examined. Notably, in the countries where Demand Response has traditionally been almost non-existent, such as Estonia, Spain, Italy, there has been at least some regulatory interest in exploring its potential. Particular interest is given to Finland, which went from preliminary development to commercially active quite rapidly, offering DR and aggregation in all markets. However, in general issues persist around a standardised baseline methodology. [22], [23]

The European countries that currently provide the most conducive framework for the development of Demand Response are Switzerland, France, Belgium, Finland, Great Britain, and Ireland. Nevertheless, there are still market design and regulatory issues that exist in these well-performing countries. Switzerland and France have detailed frameworks in place for independent aggregation, including standardised roles and responsibilities of market participants. [22], [23]

In 2017 Austria, Denmark, Germany, Netherlands, Norway, and Sweden are marked yellow, as regulatory barriers remain an issue and hinder market growth. Although several markets in these countries are open to Demand Response in principle, programme requirements continue to exist which are not adjusted to enable demand-side participation. One of the notable differences in this year’s mapping was that Germany has moved from orange status in 2015 to yellow in 2017. This is primarily due to the fact that product definitions have been updated, and an improvement in market access for new actors is expected in the near future. [22], [23]

Slovenia, Italy, and Poland are coloured orange. In Slovenia and Poland, no major regulatory changes have been made within the past couple of years that would have allowed for further Demand Response participation. Notably, Italy has upgraded its status from red in the previous SEDC Demand Response Maps to orange today, as it has slowly started to take the regulatory steps needed for a solid framework for Demand Response. However, despite the gradual opening of markets, significant barriers still hinder customer participation. For example, major sections of the market are still closed off and they lack a viable regulatory framework for Demand Response overall. [22], [23]

Spain, Portugal, and Estonia are coloured red because aggregated demand-side flexibility is either not accepted as a resource in any of the markets, or it is not yet viable due to regulation. Here we see a critical disconnect between political promises and regulatory reality. [22], [23]

To make a significant quantity of demand-side side flexibility resources available to the system, TSOs and market operators have to open the markets to aggregated load. Most countries which have opened their product requirements to Demand Response have also enabled aggregated load to participate (e.g. France, Belgium, Switzerland, Great Britain, etc.). On the contrary, other European countries opened some of their markets to load participation, but not to aggregated load, therefore disqualifying all except the largest industrial consumers from accessing these markets (e.g. Slovenia, Poland). [17], [20], [22], [23]

Further developments of DR in Europe are encouraging, with many nations rolling out smart meters as standard and the European Commission launching its Clean Energy Package (CEP) in November 2016. The CEP forms a natural partnership with renewable resources and energy efficiency. It includes the obligation for all Member States to introduce a conducive legal framework for Demand Response aggregators to foster market participation of DR, including through independent aggregators, enable their access to the market, and define relevant roles and responsibilities. [16], [22], [23]

Some general conclusions were made from SEDC:

1 The regulatory framework in Europe for DR is progressing, but further regulatory improvements are needed.
2 Restricted consumer access to DR service providers remains a barrier to the effective functioning of the market.
3 Significant progress has been made in opening balancing markets to demand-side resources.
4 The wholesale market must be further opened to demand-side resources.
5 Local system services are not yet commercially tradeable in European countries.

[22], [23]

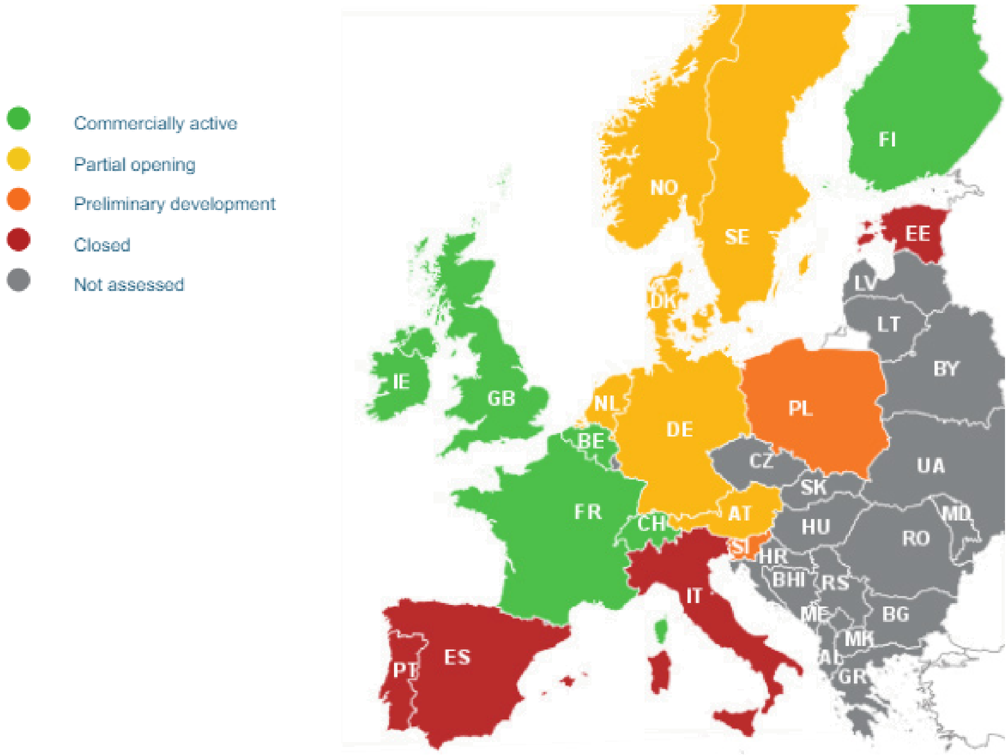

Figure 9: Map of Explicit Demand Response development in Europe 2017. Source: SEDC [22]

To illustrate the concept, some examples of aggregators are given. These include companies like Plexigrid in Spain, Voltalis in France, and Energy & meteo systems (emsys) in Germany. These aggregators play a crucial role in managing electricity demand and supply, but also for ensuring grid stability. They pool together many households or businesses, enabling them to become active players in the electricity market. This is particularly important in managing DR and integrating renewable energy sources into the grid. Table 1 gives a good overview for aggregators on the European market. Some examples will be described more in detail in the next paragraphs. The table use the following abbreviations: [17]

ASup	=	Aggregator Supplier
SaS	=	Software as Service
VPP	=	Virtual Power Plant
IndepA	=	Independent Aggregator
MC	=	Major Customer
RC	=	Residential Customer

Table 1 shows that the vast majority of aggregator services currently focuses on large customers only, rather than targeting residential customers as well. This trend can be explained by several arguments:

- Existing infrastructures: the diffusion of basic EMS in the industry, for instance, facilitates the identification of DR potentials.
- Forecasting: the baseline electricity consumption in the industry tends to be rather predictable due to commonly planned consumption profiles, and applicable large-scale RES forecasting models exist.
- Data privacy: non-disclosure agreements are already a common practise in industrial collaborations. [17]

Voltalis – France (FR)

Voltalis is a leading aggregation platform in France that serves residential customers as well as small to medium-sized businesses and industries. The company provides free installation, maintenance, and operation of smart home devices that help customers save money while generating market profits. Specifically, Voltalis equips homes with electric heating systems with a connected thermostat. This thermostat, linked to each radiator, allows for easy control and optimization of energy consumption. Voltalis technology can respond in real time to reduce the energy use of numerous appliances simultaneously when the power grid is under strain, all without compromising user comfort. [17], [24]

Energy & meteo systems (emsys) – Germany (DE)

Emsys utilities power aggregators in effectively integrating their power assets into the market. They offer a VPP solution that includes connection to various power plants, real-time data management, remote control of wind and solar farms. This for optimizing generation and avoiding negative prices, as well as forecasting, scheduling, trading on the spot market, and balancing power provision across different categories. They also handle demand-side management and balancing group management for a comprehensive solution. [16], [17], [25]

Table 1: Vast majority of aggregator services. Source: Electrical Power and Energy Systems [17]

Company	Country	Aggr./ SaS	Residential / Major Customer	Functional Roles				
VERBUND AG	AT	ASup	MC	✓	✓	(✓)	✓	✓
Next Kraftwerke	DE/EU	VPP	MC	✓	✓	✓	✓	✓
Hive Power	CH	SaS	RC, MC	✓	✓	✓		✓
BalancePower GmbH	DE	IndepA	MC	✓	✓	✓	✓	
BayWa r.e. GmbH	DE	IndepA	MC	✓	✓	✓	✓	✓
Energy & meteo systems	DE	VPP	MC	✓	✓	(✓)	✓	
GreenCom Networks	DE	SaS	RC, MC	✓	✓	✓	(✓)	✓
gridX	DE	IndepA	RC, MC	✓	✓	✓		
RheinEnergie	DE	ASup	MC	✓	✓	(✓)	✓	✓
Venios GmbH	DE	SaS	MC	✓	✓	(✓)		✓
Plexigrid	ES	SaS	RC, MC	✓	✓	✓		✓
SEAM Group	FI	IndepA	MC	✓	✓	✓	✓	✓
Voltalis	FR	IndepA	RC, MC	✓	✓	✓	✓	
Eneco CrowdNett	NL	ASup	RC, MC	✓	✓	✓	✓	✓
GreenFlux	NL	SaS	MC	✓	✓	✓		✓
ICT	NL	SaS	RC, MC	✓	✓	✓		(✓)
Peeeks BV	NL	SaS	RC	✓	✓	✓		(✓)
Sympower	NL	IndepA	MC	✓	✓	✓	✓	
EmbriQ	NO	SaS	MC	✓	✓	✓		✓
Entelios	NO	ASup	MC	✓	✓	(✓)	✓	✓
eSmart Systems	NO	SaS	MC	✓	✓	✓		✓
GridBeyond	IE/UK	IndepA	MC	✓	✓	✓	✓	
Centrica plc	UK	ASup	MC	✓	✓	✓	✓	✓
Flextricity	UK	ASup	RC, MC	✓	✓	✓	✓	✓
Kaluza	UK	IndepA	RC, MC	✓	✓	✓	✓	✓
Opus One Solutions	UK	SaS	MC	✓	✓	✓		✓
Smarter Grid Solutions	UK	SaS	RC, MC	✓	✓	✓	✓	✓

Identification of flexibility potential
Realisation of potentials
Automation
Wholesale electricity market participation
Bundling of services (aggr./supplier/BRP)

Next Kraftwerke - Europe

Next Kraftwerke operates a Virtual Power Plant (VPP) across Europe. Initially launched in Germany, Next Kraftwerke has expanded to Belgium, Austria, France, the Netherlands, and so on. (See Figure 10) This network combines numerous power producers and consumers of various sizes. The VPP utilizes real-time data to forecast energy production and consumption for the balancing group. Daily schedules are then submitted to the Transmission System Operator (TSO). Forecasted volumes are traded on the day-ahead market. Deviations from the forecast are addressed through intraday trading. Next Kraftwerke's VPP offers ancillary services, including primary, secondary, and tertiary reserves, in seven European TSO zones. Their advanced algorithms optimize schedules for networked units, allowing them to capitalize on peak pricing opportunities in wholesale markets. [16], [17], [26]

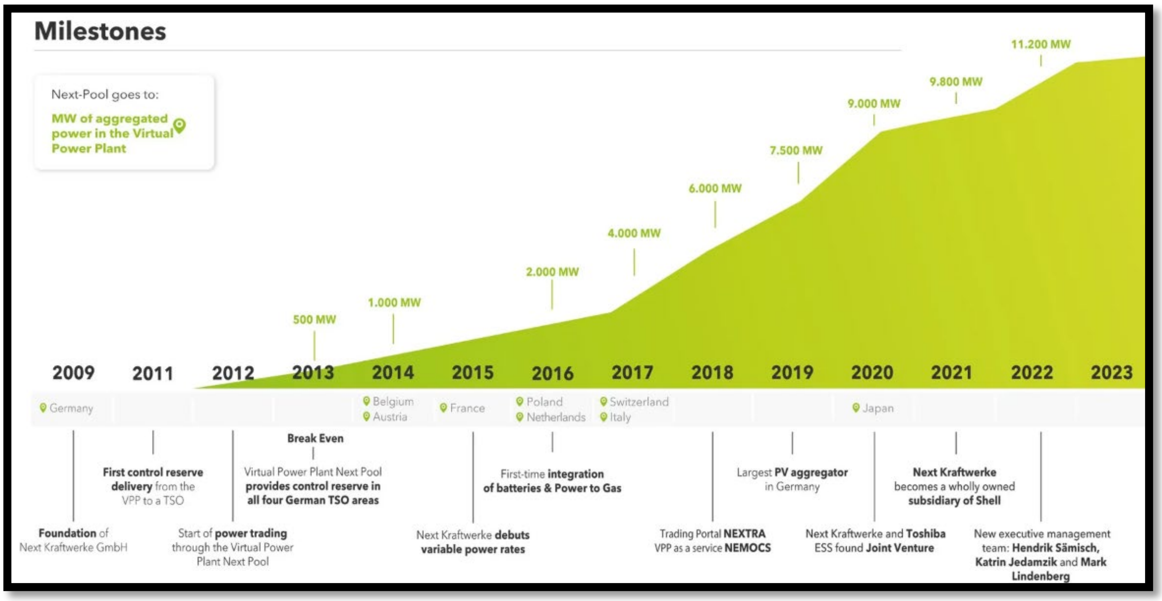

Figure 10: Evolution of Next Kraftwerke. Source: Next Kraftwerke [26]

Eneco CrowdNett – Netherlands (NL)

Eneco CrowdNett, a Dutch company launched in 2016, connects home battery owners to create a network of distributed batteries. These batteries are located on the customer's side of the meter (behind-the-meter) and managed by the homeowners themselves, who are also electricity consumers. Eneco CrowdNett offers prosumers discounted batteries in exchange for allowing them to access a part (typically 30%) of the battery capacity at any time. The network acts as a virtual power plant, providing grid services to the electricity grid operator. The grid operator can tap into the spare capacity of the home batteries to maintain balance in the electricity grid. Eneco provides a streamlined process. Coal-fired power plants take a while to scale up or down, a home battery responds immediately. [16], [17], [27]

Plexigrid – Spain (ES)

Plexigrid's solutions offer distribution grid operators the ability to optimize their grids for present operations and navigate the forthcoming energy transition. The company's reach extends to electricity retailers and aggregators as well, granting them the ability to manage DERs and deliver services to both end consumers and distribution grid operators. Plexigrid distinguishes itself through a unique approach: applications are specifically designed for the low voltage grid. Plexigrid has three unique capabilities: [17], [28]

- **End-to-end grid visibility**
  This capability provides comprehensive real-time information about every point in the grid, breaking down data silos and enhancing operational efficiency and decision-making.
- **Real-time grid analytics**
  This involves advanced analytics that monitor the grid in real-time, identifying and managing issues like overloads, unbalances and bottlenecks instantly. It reduces the need for overcapacity and enabling more efficient grid operations.
- **Flexibility management**
  This technology optimizes the use of flexible loads (like electric car charging and heat pumps) to manage grid congestion and bottlenecks in real-time, which facilitates the integration of renewable energy sources and the deployment of electric vehicle charging stations efficiently.

2.2 Comparison to other protocols or systems for DR

The term "protocol" refers to an established set of rules governing the format and interpretation of information exchanged between two devices at the application layer. Sometimes is the term "protocol" referred as a "messaging protocol" because it carries the information necessary for the exchange of data. [29]

In this section other protocols or systems useable for DR in Europe are described. To choose the different protocols or systems for DR, a paper is used. [30] The original table describes topics covered by ontologies and other standards related to energy and DR. The selection is refined by examining protocols used in industry markets in Europe and if they support demand response. Table 2 shows the selection and the scope of each standard.

Table 2: Standards used in Europe and support demand response Source: Own elaboration based on SEST 2020 & DELTA [30], [31]

Protocol / Standard	**Scope**				**Communication between utility and DER controller?**	**Website**
	Events	Measurements	Equipment	Products		
OpenADR					YES	https://www.openadr.org/resources
Universal Smart Energy Framework (USEF)					YES	https://www.usef.energy/news-events/publications/
Facility Smart Grid Information Model (FSGIM)					YES	https://www.iso.org/obp/ui/#iso:std:iso:17800:ed-1:v1:en
S2 standard / EN 50491-12-2					YES	https://s2standard.org/wpcms/wp-content/uploads/2023/09/S2-Whitepaper-202309-1.pdf
IEC/EN 61970 or the Common Information Model (CIM)					YES	https://www.entsoe.eu/digital/common-information-model/
IEC 62746					YES	https://webstore.iec.ch/publication/22279
IEC 61850					YES	https://iec61850.dvl.iec.ch/
DNP3					YES	https://www.dnp.org/About/Overview-of-DNP3-Protocol
OCPP					NO	https://openchargealliance.org/protocols/open-charge-point-protocol/
EN 16836-2					NO	https://standards.globalspec.com/std/10058688/en-16836-2

The terms Events, Measurements, Equipment and Products are used to define the scope of the Protocol/Standard standards and ontologies in the context of Demand Response (DR) systems.

- **Events** – Is it compatible to send and receive in events for exchange information? Refers to the possibility for the energy system that may require a response or action. This could include changes in energy prices, load changes and demand response events.
- **Measurements** – Are there measurement possibilities?
  Refers to the data collected from the energy system, such as energy consumption, generation, voltage, frequency, and other relevant metrics. These measurements are essential for monitoring, analysing, and controlling the energy system.
- **Equipment** – Do they provide equipment?
  Refers to the physical devices and assets involved in the energy system.
- **Products** – Is it compatible with energy services or tariffs?

It is important to note that some data exchange systems are designed especially for the consumer side. For example, OCPP is designed for communicating between charging stations (consumer side) and a distributed energy resources (DER) controller. Another example is EN 16836-2, a standard that facilitates communication between the smart communities (esp. residential) and the DER controller. Figure 11 clarify this. [30], [31], [32]

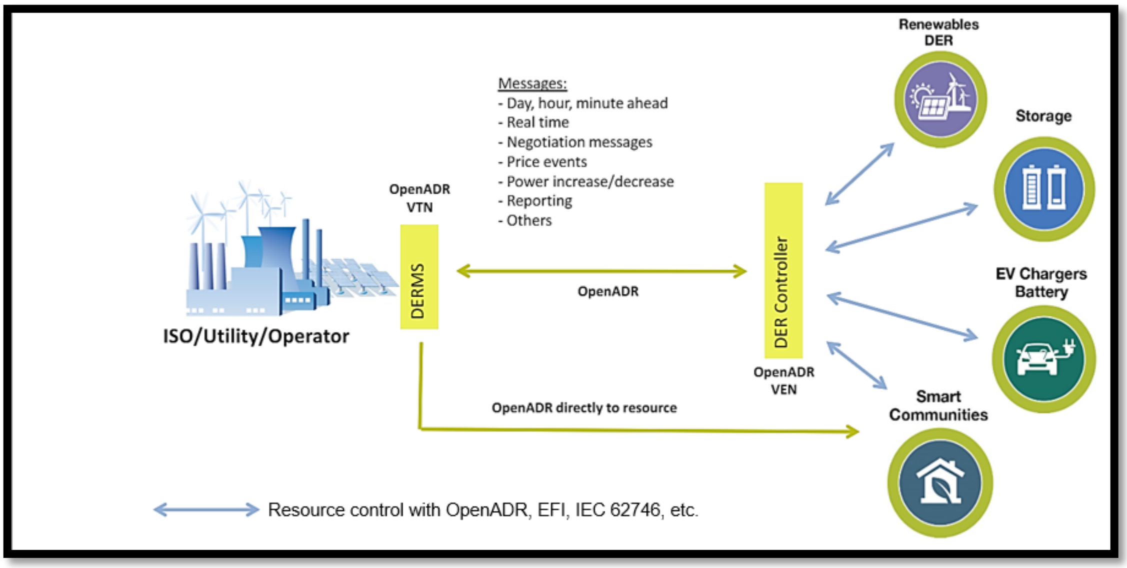

Figure 11: Communication layers clarified. Source: OpenADR Alliance [33]

Manufacturers often promote the language versatility of their smart devices, such as inverters, thermostats, or battery systems. However, this claim can be misleading. While these devices may use common protocols like Modbus or BacNet, they might not be directly compatible with smart grid protocols like IEEE 2020.5, OpenADR, or IEC 61850. This can necessitate additional conversion, potentially leading to extra expenses for the end-user. The selection of an appropriate protocol is crucial to ensure seamless communication and interpretation of messages between devices. [29]

It is important to note that the specific contents of a protocol's information model might restrict its use beyond a certain domain. Take OpenADR as an example. OpenADR is equipped with the necessary data to interact with DR. However, it lacks the information model for smart inverters that can control distributed energy resources for example. Smart inverters necessitate a unique set of functionalities determined by local grid codes. These include automatic control of output based on local voltage, modifications to power factor and reactive power output, etc.

OpenADR is suitable for communication exchange between a distribution utility and a DER, but not as a smart inverter. To address this issue, a conversion implementation would be required to control the smart inverter between the two. This would allow a more comprehensive system because it can act as a communication and a smart inverter device. A drawback of this approach is the increased cost associated with implementing these specific individual system solutions. [29], [34] Selected from Table 2, the next subsections describe short the standards considered most relevant for the DR domain in Europe. Some popular standards from the USA are also described. Detailed working principles are out of the scope of this thesis.

2.2.1 Universal Smart Energy Framework (USEF)

The USEF outlines the market dynamics for flexible energy use, facilitating its commoditization and market trading. It defines the roles of all stakeholders within the energy system and explains their interactions. The framework also details service capabilities, connectivity, data exchange, and control mechanisms. Through collaboration, USEF partners tackle the challenges of an integrated energy system, benefiting both new and conventional energy companies as well as consumers. [30], [31], [35], [36]

2.2.2 Facility Smart Grid Information Model (FSGIM)

The Facility Smart Grid Information Model (FSGIM) standard is a component of a wider set of standards designed to support the development and implementation of a smart electric grid. FSGIM offers an abstract representation of the Smart Grid from a facility's viewpoint. It establishes a unified framework to guide the development of control technologies within a facility, ensuring they align with the requirements of a smart grid environment. While FSGIM itself is not a protocol, it can assist other protocols in adapting to the smart grid. [30], [31], [37]

2.2.3 S2 standard (Energy Flexibility Interface (EFI)) / EN 50491-12-2

The Flexiblepower Alliance Network (FAN) and Dutch Organization for Applied Scientific Research (TNO) have collaborated on Energy Flexibility Interfaces (EFIs) for many years, leading to the development of the S2 standard. This resulted in the S2 standard, which is promoted by the S2 consortium S2, an official European standard for energy management, known as EN 50491-12-2. This standard enables the control of various smart appliances, such as heating systems, air conditioning, solar panels, and electric vehicles. EN 50491-12-2 does not model the smart devices themselves but focuses on the available energy flexibility and its utilization by smart grid technology. The goal of this standard is to establish a common language for energy flexibility, ensuring future-proof interoperability and simplicity. S2 has already been proven in EU Projects like

- H2020 InterFlex[1]
- Energie Koplopers[2]

[30], [31], [38], [39]

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[1] https://interflex-h2020.com/

[2] https://sympower.net/energie-koplopers/

Many existing proprietary protocols, such as Zigbee, OpenADR, KNX, and Matter, are already in place to control devices. The purpose of S2 is not to replace these protocols but to introduce an energy flexibility application model that current protocols lack. With its specific focus on energy management, S2 addresses a different niche. As illustrated in Figure 12, S2 does not aim to replace features provided by other protocols, such as device configuration, firmware updates, and support for device apps. Instead, S2 can enhance existing protocols by adding energy flexibility management capabilities. [30], [31], [38]

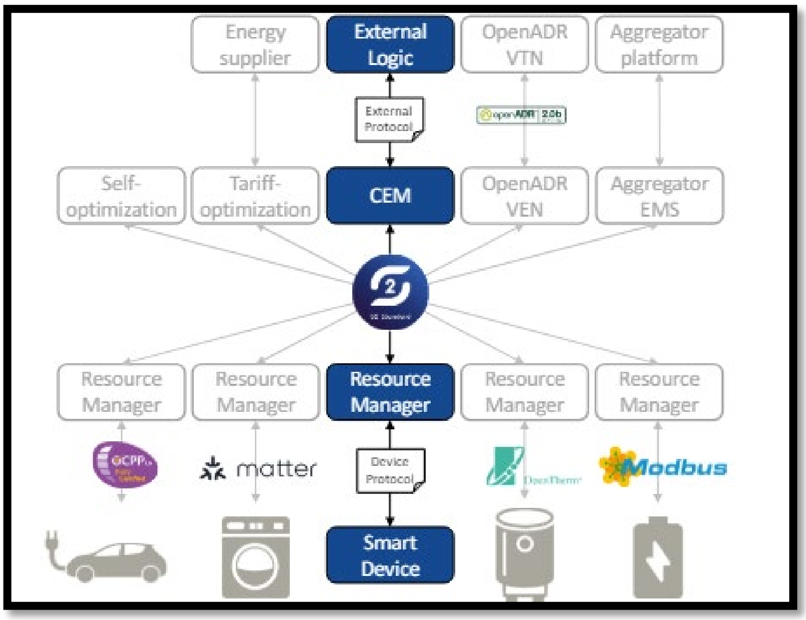


Figure 12: Place of S2 in function of other protocols. Source: S2 White Paper [38]

2.2.4 IEC/EN 61970 or the common information model (CIM)

This standard includes the IEC 61970 which lays down the common information model (CIM). The CIM is an abstract framework representing all key objects in an electric utility enterprise relevant to utility operations. It offers a standardized depiction of power system resources. The standard outlines data models to facilitate information exchange between systems, supporting business functions as well as the operation and planning of the interconnected electric grid. [30], [31], [40]

The CIM defines the primary resources necessary for managing the electric system. It is a three-layer domain model intended to support power management processes, including outage management, asset management, and customer information management. However, the DELTA project, part of the European Union's Horizon 2020 research and innovation programme, suggests that the CIM is not ideally suited for Demand-Side Management (DSM) due to its insufficient modelling at the last mile of the supply chain. The project name **DELTA** stands for "Future tamper-proof **D**emand r**E**sponse framework through se**L**f-configured, self-op**T**imized and coll**A**borative virtual distributed energy nodes." [30], [31], [40]

2.2.5 IEC 62746

IEC 62746 is a communication standard to facilitate interaction between customer energy management systems and power management systems. This standard, what OpenADR 2.0 specifications is based on, aims to bridge the gap between the "Grid" and "Active Customers" by enabling flexibility in energy management. The key aspects of this standard are architecture model from a logical point of view, details of the communication and describing the requirements for messages and information to be exchanged. [30], [31], [39]

2.2.6 DNP3 Protocol

DNP3 is a communication protocol designed for efficient data exchange between devices from point A to point B, particularly over serial and IP network. Although primarily utilized in the utilities sector (electricity, water), its capabilities extend to various industries. The protocol involves communication between two types of devices: a master station and a remote unit. [41], [42]

- Master station
  Typically a computer or a network of computers situated in a central control facility, this component oversees the communication network. [41], [42]
- Remote unit
  Often deployed in the field, these devices gather data from various field instruments and sensors. They transmit this information to the master station or interact with other compatible field devices like Remote Terminal Units (RTUs) or flowmeters. [41], [42]

  An example explains the master station and remote unit. Consider a typical electric utility: A central operations center (MASTER) serves as the nerve center, collecting data from all substations within the power grid. A high-performance computer system stores this incoming data and presents it in a user-friendly format for operators. Each substation (REMOTE UNIT) acts as a data collection point, housing devices like circuit breaker monitors (open/closed status), current sensors (amperage measurement), and voltage transducers (line voltage measurement). These substations contain numerous devices requiring monitoring. [41], [42]

This protocol is particularly used in the United States and Canada. In summary, it enables the transportation of basic data securely and efficiently, thanks to features like TLS encryption and robust authentication. DNP3 primarily focuses on data while largely leaves contextual information. [41], [42]

2.2.7 IEC 61850

The IEC 61850 standard series defines communication protocols for real-time interaction between devices in electrical systems, fulfilling stringent operational requirements. Primarily embraced in Europe and Asia, this standard offers distinct benefits over alternatives, but its complexity and the lack of rigorous certification for DER applications pose challenges. The Utility Communications Architecture International Users Group (UCAiug) oversees testing and certification procedures for IEC 61850 implementations. The standard is fundamental to communication within electrical substation automation systems. Its notable features encompass data modelling, rapid event transmission, reporting mechanisms, and sampled data transfer. [29], [43]

2.2.8 IEEE 2030.5

IEEE 2030.5 is an application layer specification formerly referred to as Smart Energy Profile 2.0 (SEP 2.0). It was developed as a secure communication protocol to integrate consumer's smart devices into the smart grid, including smart loads, electric vehicles, and DERs. The protocol reduces communications architectural challenges by using the familiar Internet Protocol (IP) and supporting a variety of protocols at the physical layer (including Ethernet, Wi-Fi and low-power radio technologies). It is designed to use the modern internet for transport of its messages between devices. It includes also "function sets" for price communication and for DR. [29], [34], [44], [45]

Presently, no DR vendors support IEEE 2030.5 natively. Therefore, network gateway devices must be used at the DER to adapt from 2030.5 to local DR resources. According to the available bibliography analysed in this Thesis, this protocol is not active in Europe now. Some European countries show only interests. [45] Now, it is only in use in United States, Australia and Canada. For example: IEEE 2030.5 has been selected as the default application-level protocol for communications between a utility and an aggregation for controlling inverters in California. This is even captured in the California grid code, called Rule 21. The Rule 21 has three different scenarios for using IEEE 2030.5 to communicate with a DER:

1. Direct-to-inverter communications
2. Inverter communications mediated by an energy management system controlling the DER
3. Inverter communications mediated by a DER operator/aggregator

It also adopts many of the device models from IEC 61850 to provide a wide-area protocol for DER communications. [29], [34], [44], [45]

2.2.9 OpenADR vs IEEE 2030.5

OpenADR and IEEE 2030.5 are distinct protocols with separate structures and specifications. While they both address demand response capabilities, their approach differ. In section 2.5.4 technical terms around OpenADR were described. In section "2.1 The aggregator role" terms like DER and VPP were explained. This section uses these terms and presents a comparison using the OSI Model and architecture diagrams.

2.2.9.1 Using the OSI model to compare

The Open Systems Interconnection (OSI) model is a conceptual framework used to describe the functions of a networking system. It divides network communications into seven abstract layers, each with specific tasks. Most protocols can be mapped to one or more layers the seven-layer OSI stack. Comparing the various communication protocol standards to the OSI seven-layer Reference Model makes it easier to see how they relate to each other and what interfaces are needed for them to interoperate. As exercise IEEE 2030.5 will be compared to Open ADR 2.0 (Table 3). [34]

Table 3: Comparing IEEE 2030.5 and OpenADR with OSI model. Source: Own elaboration based on source EPRI [34]

	Layer	Name of the Layer	IEEE 2030.5	Open ADR 2.0
Application Domain	7	DER/DR Data Model	IEC 61850-7-420 IEC 61968-5	OpenADR v2.0 Profiles
		Application	HTTP	HTTP XMPP
	6	Presentation	TLS	TLS 1.2
Network/ Transport Domain	5	Session	Any (e.g. TCP session Management)	Any (e.g. SSL)
	4	Transport	TCP	TCP
Physical Domain	3	Network	IP	IP
	2	Data Link	Any (e.g. IEEE 802.2)	Any (e.g. IEEE 802.2)
	1	Physical	Any (e.g. IEEE 802.1x)	Any (e.g. IEEE 802.1x)

The most significant differences lie in the higher layers, like the application domain. IEEE 2030.5 is geared towards broader DER management, while Open ADR 2.0 focuses specifically on demand response and energy management. At the application protocol, Open ADR 2.0 offers more flexibility by supporting both HTTP and XMPP. Both IEEE 2030.5 and Open ADR 2.0 are designed to facilitate communication and interoperability within smart grids. The choice between them often depends on the specific use case and the desired level of control over distributed energy resources.

2.2.9.2 Using the architecture diagrams to compare

In architecture diagrams like the one shown in Figure 13 or Figure 14, all information exchanges where protocols generally might operate are indicated by arrows. When illustrating the application domain of a specific protocol, the areas in which it typically operates are indicated by blue arrows, while the areas in which it is not typically used are greyed out.

The entities included in a typical electrical architecture diagram are:

- **Transmission System Operator (TSO)**
  Manages high-voltage energy transmission at a regional level.
- **Distribution System Operator (DSO)**
  Manages lower-voltage electricity distribution to local consumers. Connected to TSO systems.
- **Aggregator**
  Intermediaries between TSOs or DSOs and consumers. An aggregator manages groups of resources. It acts as a single entity when participating in an energy market.
- **Distribution Energy Resource (DER)**
  Examples of DER include solar PV systems, energy storage systems, and DR technologies.
- **DER Provider**
  DER providers are the companies or individuals that own and operate DERs. They can range from homeowners with a few solar panels to large commercial and industrial customers .
- **Site-Level Management System**
  These are software and hardware systems that control and optimize the operation of multiple DERs at a single site, like a factory, hospital, or university campus.
- **Component of DER**
  Individual parts of a DER, like battery management systems, inverters, or meters

[34]

If the architecture diagrams compared:

- OpenADR demonstrates greater compatibility at higher architectural levels. For instance, OpenADR facilitates communication between Transmission System Operators (TSOs) and Distribution System Operators (DSOs), This is a compatibility that is not present in IEEE 2030.5.
- OpenADR enables broader communication channels with aggregators. Its purpose-built is to support aggregation (DER groups) for internal system-to-system communication. OpenADR can interface with aggregators from the DSO, DER provider, and Site-Level Management System, while IEEE 2030.5 only connects with aggregators from the Site-Level Management System.

- IEEE 2030.5 is not presently designed to facilitate direct communication between utilities and aggregators. It lacks the functionality for managing groups of DERs and only allows for pass-through messaging.
- Both protocols are not designed for the communication between Distribution Energy Resource (DER) and components of DER. This reveals a gap in both standards, necessitating the use of other systems.

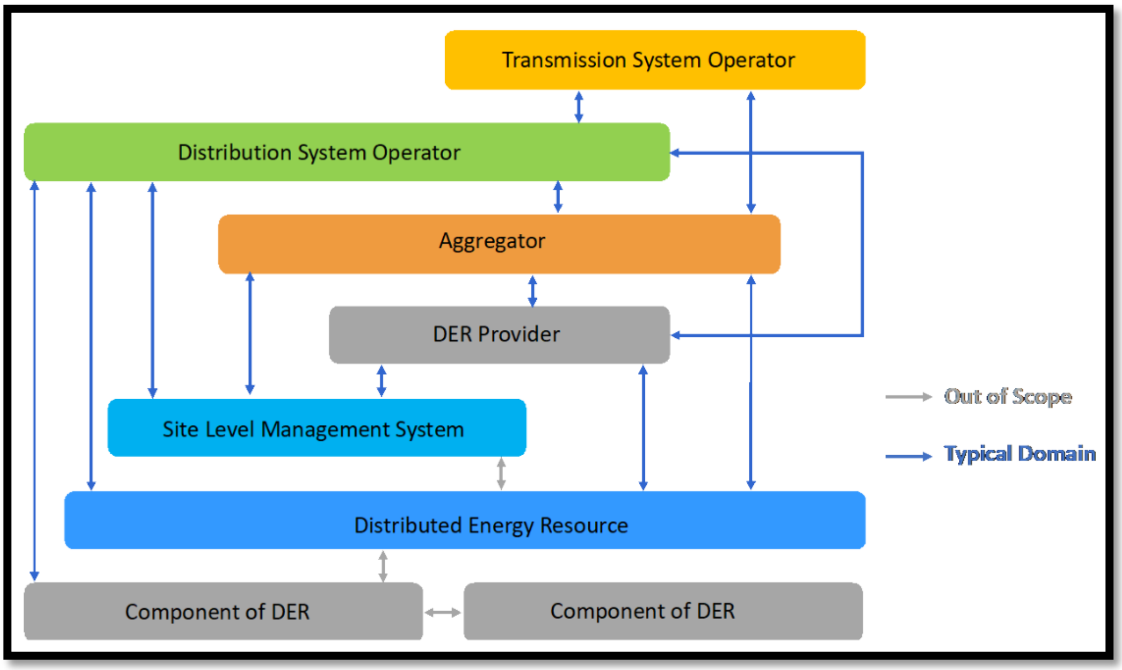


Figure 13: OpenADR architecture overview - typical domain. Source: EPRI [34]

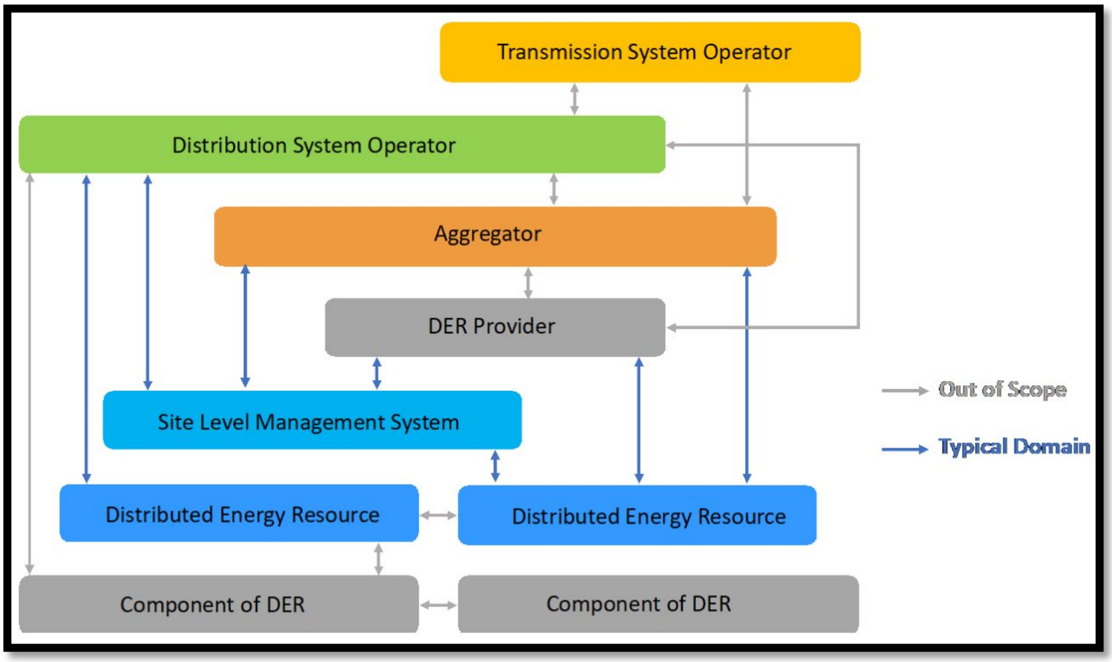


Figure 14: IEEE 2030.5 architecture overview - typical domain. Source: EPRI [34]

2.2.9.3 Conclusions of the comparison

In conclusion, both OpenADR and IEEE 2030.5 can play important roles in the landscape of smart grids and energy management. While they share the common goal of enhancing communication and interoperability, their distinct focuses and technical characteristics make them suitable for different applications. OpenADR, with its emphasis on demand response, excels in facilitating interactions between utilities, aggregators, and various energy resources. Its flexibility in supporting multiple communication protocols and its compatibility with higher architectural levels make it a versatile choice for DR. On the other hand, IEEE 2030.5 primarily geared towards managing distributed energy, also offers a standardized framework for communication and control within smart grids. However, its current limitations in direct communication with aggregators and utilities highlight areas then DR. [34], [45], [46]

Ultimately, the choice between OpenADR and IEEE 2030.5 depends on the specific requirements of the energy management system, the desired level of control over distributed energy resources, and the existing infrastructure. Table 7 provides key specifications to help guide this decision. [34], [45], [46]

- Adoption: Summary of how widely the protocol is used, including insights on its market presence and use in products.
- Devices and Technologies: An overview of the types of devices supported by the protocol and the type of functions it supports.
- Implementation: Key words for description of the protocol's workings, complexity, and general implementation requirements.
- Cyber Security Features: Overview of the protocol's security measures, including whether these are included in conformance testing.

Table 4: Key specifications for IEEE 2030.5 and OpenADR. Source: Own elaboration based on [34], [45], [46]

Description	**IEEE 2030.5**	**OpenADR**
Adoption	▪ Primarily designed to manage Distributed Energy Resources (DERs) ▪ Used in United States, Australia and Canada	▪ Primarily designed for Demand Response (DR) ▪ Widespread in United States and Japan, but also more and more in Europe from the U.K. to Germany, as well as the Netherlands to Croatia
Devices and technologies	▪ Especially designed for communications with DER resources ▪ Supports a variety of consumer devices, including energy storage, load control devices, aggregators, and cloud servers	▪ Especially designed for aggregated DR resources, not individual devices ▪ Supports also different types of energy management systems, such as gateways and controllers
Implementation	▪ XML is used for encoding its commands and data ▪ Client-server network architecture ▪ Supporting only HTTP in application domain	▪ Services expressed as XML. Messages transported over HTTP ▪ Supporting both HTTP and XMPP in application domain
Cyber security	▪ Secured using HTTP over Transport-Layer Security (TLS). This is also called HTTPS ▪ Digital certificates to authenticate their identity	▪ Transport Layer Security (TLS) ▪ High secure option “XML signatures” for securing all or part of the XML message payloads ▪ Certificates for clients and servers

As the energy landscape continues to evolve, both protocols are likely to play crucial roles in shaping the future of smart grids and energy management, contributing to a more efficient, reliable, and sustainable energy system.

2.3 DER and possible communication standards

Section 2.1, discussed distributed energy resources (DER). Also, most common communications standards suitable for demand response were described in section 2.2. To clarify the distinct applications of various protocols, a differentiation is made between two categories of distributed energy resources (DERs):

- **Direct DER Management**
  Large-scale resources such as solar farms and wind farms or grid-scale battery storage, typically owned by utilities or corporations.
- **Distributed Decision DER Management**
  Smaller-scale resources like residential solar panels, batteries, generators, and electric vehicles, typically owned by customers or aggregators. [46]

Figure 15 gives a good summary of the differences between Direct and Distributed Decision DER Management**.** It is important to note that the precise boundary between these categories is still evolving and will likely be determined by the industry based on factors like implementation and ownership models.

Large-scale DERs, such as utility-scale solar or wind farms, benefit from established communication protocols like DNP3 and IEC 61850. These standards offer integration with existing Supervisory Control and Data Acquisition (SCADA) systems. SCADA is a system that enables real-time monitoring and control of large-scale assets. In contrast, smaller-scale DERs, like residential solar panels or electric vehicle chargers, often rely on information-based communication systems. OpenADR standard excels in this domain. Bridging the gap between these two approaches is IEEE 2030.5. This standard aims to foster interoperability between diverse DER technologies, regardless of their scale or complexity. A disadvantage of IEEE 2030.5 is, as mentioned in section 2.2.9.2, the limited compatibility at higher architectural levels. IEEE 2030.5 does not facilitate communication between a Transmission System Operators (TSOs) and a Distribution System Operators (DSOs), or between a DSO and an aggregator. [46]

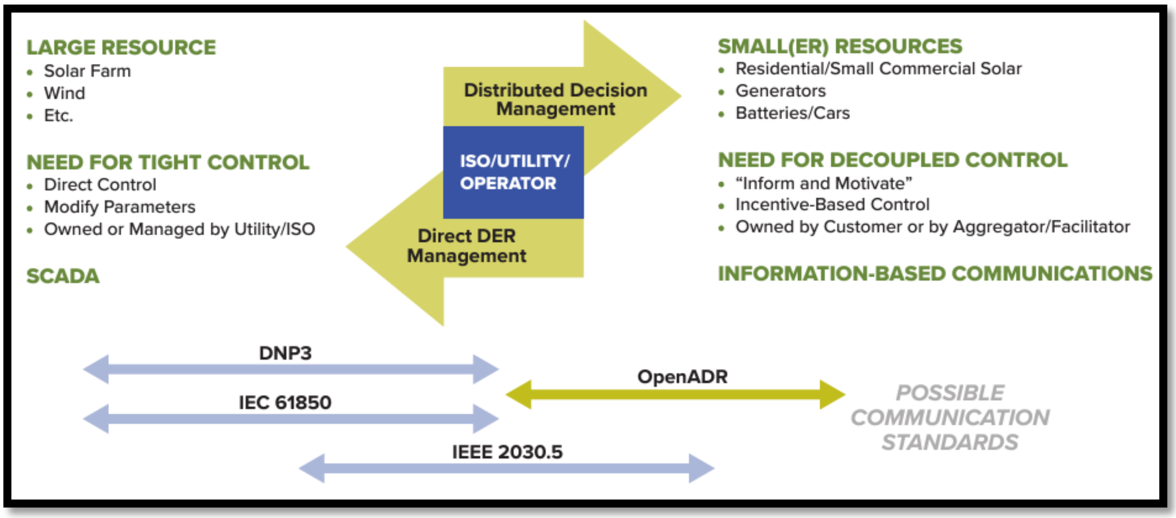


Figure 15: Standards suitable for direct and or distributed decision management. Source: OpenADR Alliance [46]

Focusing on OpenADR, it aligns more closely with Distributed Decision Management. Advantages of Distributed Decision Management using OpenADR are:

- Customer autonomy: Customers maintain control over their energy resources.
- Utility influence: Utilities incentivize desired customer behavior.
- Clear boundaries: Utilities retain a defined point of responsibility.
- Enhanced security: Cyber security risks are mitigated.
- Cost efficiency: Implementation and operation costs are reduced.
- Simplified integration: Integration with existing systems is facilitated.
- Leveraging standards: Existing standards and products can be utilized.
- Reduced time-to-market: Solutions can be deployed more quickly.

[46]

2.4 Why choosing OpenADR

OpenADR is emerging as a leading standard for demand response programs due to its numerous advantages. However, it is important to acknowledge the current challenges in adoption, particularly within Europe. The availability of OpenADR-compatible hardware, a crucial component for implementing the standard, is limited due to a lack of widespread demand in Europe. At the moment of writing, the United States has a significantly wider availability of OpenADR-compatible hardware. This scarcity can pose a challenge for organizations looking to adopt OpenADR in Europe for their demand response initiatives. [47], [48]

Despite this obstacle, the benefits of OpenADR make it a compelling choice for demand response programs. All advantages of OpenADR can be found in section 2.5. The most interesting advantages are here highlighted. The standard facilitates bi-directional communication, enabling utilities to not only send demand response signals but also receive telemetry data from resources. This feedback loop provides valuable insights into the performance of demand response events and allows for data-driven optimization.

OpenADR enables targeted price and energy information delivery based on various criteria. Targeting can be refined by area, zip code, self-identified group IDs, resource IDs, VEN IDs, and other criteria. Refer to section 3.4.4.1.2 for a more clearly explanation. This granularity allows for tailored demand response signals to specific groups of resources, enhancing the effectiveness of demand response events.

Furthermore, OpenADR provides a clear demarcation point between utility controls and customer-owned equipment. This separation ensures that utilities have the necessary control over grid operations while respecting the autonomy of customers over their own resources. Since OpenADR is an open standard, it can be easily integrated with existing protocols and systems like an already existing DER controller. [46]

OpenADR is also designed to accommodate future transactive control functionalities. This means that in addition to traditional demand response signals, utilities will be able to include quotes, tenders, and delivery services within their communications. This opens new possibilities for dynamic pricing and market-based demand response mechanisms. [49], [50]

Several prominent standards are available for managing load shifting and demand response applications. These include OpenADR, DNP3, and IEEE 2030.5, and several others that are used in specialized setups. A deep dive comparison of these standards would require its own full research study, but section 2.2 gives a summary for protocols compatible with demand response. GridFabric, a company deeply rooted in the development of OpenADR, asserts that OpenADR is the most established and preferred choice for demand response and load shifting initiatives. GridFabric's founders, previously known as Nebland software, were the creators of the original OpenADR software and have continued to contribute to its advancement. Their extensive experience in this field is evident through their involvement in numerous integrations with OpenADR and other relevant standards. [45], [51]

While IEC 61850 is increasingly the standard of choice for communication within power utilities, its current implementation does not comprehensively support the dynamic information exchange required for Virtual Power Plant (VPP) functions like aggregation, scheduling, pricing, and product prediction. Specifically, the IEC 61850-7-420 sub-standard provides typical communication interfaces between DERs and VPPs. Unfortunately, it lacks full support for aggregation. [52]

Why not using IEEE 2030.5? According to OpenADR Alliance and the gathered information from section 2.2.9, OpenADR and IEEE 2030.5 serve complementary roles within the smart grid ecosystem. While IEEE 2030.5 is a standard designed for interoperable communication between utility control systems and edge devices, OpenADR focuses on facilitating DR and DER management. The two standards have distinct applications. OpenADR typically requires a gateway device, building energy management system (EMS), or aggregator to translate utility requirements into specific device actions. Conversely, IEEE 2030.5 is primarily intended for direct device control. [46]

Also, as another study of QualityLogic, the recommendation for using DR from utility to aggregator is OpenADR. Table 5 shows the recommendations of communication protocols for providing effective longevity in different cases. QualityLogic is a company who is specialized in advising utilities, vendors, alliances, research labs and regulators on the capabilities and implementation of communications protocols or specific DER protocol standards. QualityLogic occupies a unique role in the development and implementation of communications protocols for DER management by vendors and utilities. Effective longevity provides the maximum in-service lifetime for the device industry and means that you will have the minimum lifetime cost associated with the communication protocol. The protocols used in this table are short described in section 2.2. [29]

Table 5: Recommended communication protocols and alternatives in different use cases. Source: own elaboration based on source QualityLogic [29]

Use case / Application	**Recommended protocol(s)**	**Alternative protocols**
Utility Scale Solar/Storage - SCADA Control	DNP3 IEC 61850	IEEE 2030.5
DR: Utility to EMS/Aggregator	OpenADR	IEEE 2030.5
Solar Smoothing	DNP3 IEC 61850	IEEE 2030.5
Solar Shaping	IEEE 2030.5	DNP3 IEC 61850
Duck Curve Mitigation	IEEE 2030.5	DNP3 IEC 61850
Black Start - Wildfire Prevention	IEEE 2030.5	
Frequency Regulation	DNP3 IEC 61850	IEEE 2030.5 OpenADR
CA Rule 21 Solar and Storage	IEEE 2030.5	DNP3 IEC 61850
V2G Applications: Utility to EVSE/PEV/Gateway	IEEE 2030.5	DNP3 IEC 61850 OpenADR OCCP ISO 15118

As detailed in section 2.3, OpenADR aligns more with information-based communication systems, in which energy systems are managed by consumers or aggregators. In contrast to protocols like DNP3 or IEC 61850, which emphasize direct control, OpenADR focuses on decoupled control systems for facilitating the integration of smaller resources (generators, charging stations for cars, commercial solar panels, …).

In conclusion, while the limited availability of OpenADR-compatible hardware in Europe presents a challenge, the benefits of the standard in terms of targeted communication, bi-directional data exchange, future transactive control capabilities, and clear demarcation of responsibilities make it a promising choice for demand response programs. Increased demand for OpenADR in Europe will likely lead to greater availability of supporting hardware, accelerating its widespread adoption.

2.5 Introduction to Open Automated Demand Response (OpenADR)

2.5.1 Working principle of OpenADR

OpenADR is a communication protocol that enables automated demand response programs. It uses web services to securely exchange messages between utilities and their customers. The goal of the OpenADR protocol is to provide timely and reliable demand response events into load reductions or shifts by the participants, without manual intervention. It is a two-way communication although not all functions are symmetrical. Some signal elements (like the price of the electricity) are meant to travel mainly in one direction. It essentially streamlines the interaction between utility companies and their customers, allowing a grid that operates with increased efficiency and responsiveness. [50], [53]

OpenADR can also be described as a data model for communicating events such as DR signals, price schedules, and grid stability between a DR server and DR clients. [50], [53]

- A DR server, known as a Virtual Top Node (VTN) is generally located at the utility side. It is mostly operated by an energy supplier or aggregator.
- A DR client, known as a Virtual End Node (VEN), is part of the demand side control system. A VEN can be a gateway that controls devices at the customer site.

Figure 16 clarify the relationships between VTNs & VENs in OpenADR. Here are VENs described as gateways and VTNs as service providers or aggregated loads. In other terms, OpenADR can be envisioned as a web browser (VEN) and website hosting server (VTN) combination. The VEN frequently polls the VTN by sending a data update request to the server. Upon receiving this message, a security exchange is started and the VEN and VTN connect. Now the information elements in a specific format will flow from the VTN to the VEN and the VEN confirms receipt and acts on the messages.

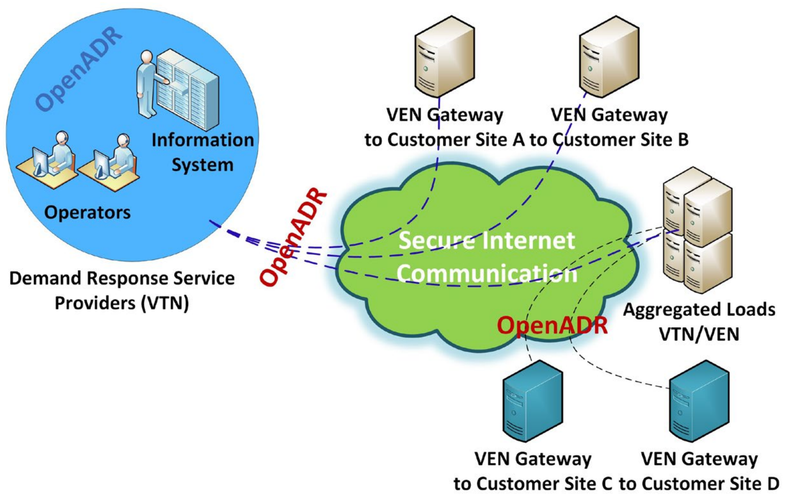


Figure 16: Relationships between VTNs & VENs in OpenADR. Source: REDEC [53]

It is important to clarify that OpenADR itself does not trigger demand response events or dictate load reduction amounts. OpenADR is really the carrier of that information from the utility to the downstream resources. The utility or grid operator decides when to initiate an event. The specific load adjustments are determined based on individual customer agreements or device capabilities. There are many different locations where this sort of logic, the decision about when an event is needed and what should be done, can exist. Figure 17 shows the possible locations for DR logic events. [33]

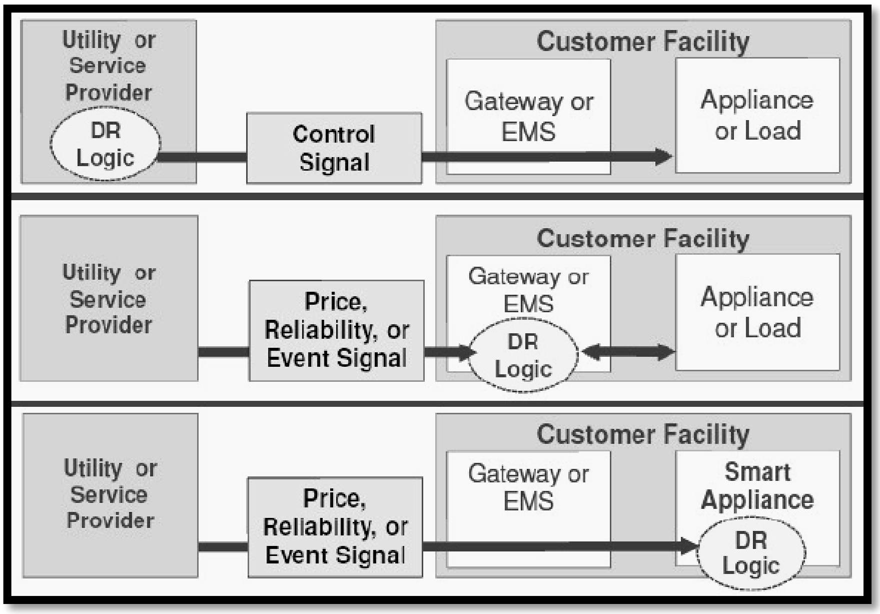


Figure 17: Locations of DR logic can exist. Source: Akuacom & Lawrence Berkeley National Laboratory [54]

2.5.2 A brief history & evolution of OpenADR

In the early stages of demand response programs, before the 2000s, the focus was on securing additional power (MWh) or capacity (MW) during periods of high unusually high prices or capacity shortages due to unexpected consumer demand. Back then, the approach was rather simple in principle. Utilities targeted large energy consumers, minimizing participants while maximizing potential restrictions. [50], [55]

These programs were largely manual. Facilities lacked automation, requiring facility managers to manually adjust consumption upon request. During the onboarding, experts would evaluate the facilities together with the resident staff to determine the most effective response strategy. Often, this resulted in manual checklists for on-site operators, ensuring a predictable response. Note that factories and other places still control some things manually. Factories for example cannot be expected to automatically adjust the electricity load without any human interaction and authorisation. [50], [55] Three key reasons summarised why manual demand responses will be not sufficient for the future: [50], [55]

- **Absence of feedback**
  Utilities had to rely on readings in their substations, overall power consumption, and data based on previous experiences. This might not enough to be sustainable over time. [50], [55]
- **Scalability constraints**
  Controlling larger consumers through manual processes is constrained. Even with dialling machines and fax machines is the scalability too limited. [50]
- **Lack of standardization**
  Each utility essentially built its own program with different parameters. While this is in principle not a bad thing, it also means that suppliers and integrators would customize solutions as needed. This causes higher costs and long implementation timelines. [49], [50]

The lack of real-time feedback, scalability and the inconsistency across programs necessitated a shift towards better automation and improved communication infrastructure. Another important event was the California energy crisis of 2002 that ran into supply shortages and increased energy prices. Rolling blackouts circulated around the state to make up for the shortages which affected businesses and private entities alike. It revealed vulnerabilities in the electricity grid and highlighted the need for new technologies with flexible demand management strategies. After the crisis was contained, the California Energy Commission (CEC) identified the need for a better, faster, and more scalable communication mechanism for demand response (DR). In particular, to eliminate the need for rolling blackouts. [49], [50]

The initial focus of OpenADR 1.0 was on enabling automated communication for price-based DR programs, allowing customers to adjust their electricity consumption based on real-time pricing signals. The first version of OpenADR was developed for the United States, but global developments in smart grid have led to the use of OpenADR in international deployments. It was also not recognized as an international standard. That is why OpenADR 2.0 was developed for more internationally standardization and has a testing and a certification program. OpenADR 2.0 is more based on a formal standard. It is backed by a industry alliancea and is also building on the framework of OpenADR 1.0 to support growing global interest and advanced features. Table 6 gives a summarize of the important differences between OpenADR 1.0 and OpenADR 2.0. [50], [56], [57]

Table 6: Differences between OpenADR 1.0 and OpenADR 2.0 Source: Own elaboration based on [56], [57]

OpenADR 1.0	OpenADR 2.0
Limited number of vendors	Large, rapidly growing ecosystem of vendors
No certification program	Test tool, test plan & certification
Lacks test tool and harness for implementors	Expanded architecture to include pricing, telemetry and other services
Public specification based on standards of the state of California	Public specification based on formal industry standard
Not a national or international standard	Based on OASIS standard
Focussed on retail programs, pilots for wholesale markets and ancillary services	Services for retail and wholesale markets, operations and distributed energy resources
Limited feedback capabilities	Explicit feedback capabilities and enhanced schedule, dynamic pricing, and other services.
Geared towards to local demand response programs	Flexible to adjust to most demand response programs

While complex specifications were often the norm, the industry sometimes benefited from simpler profile definitions. That is why the profile specification of OpenADR 2.0 is divided into two parts (Figure 18):

- **Profile A (OpenADR 2.0a)**
  Profile A is designed for resource-constrained, low-end embedded devices that can support basic DR services and markets. Profile A is supporting standard DR programs. This profile is targeted at limited resource devices and simple DR applications. It is limited to so-called simple signals, in which the signal content can only include discrete numbers from 0 to 3. These numbers could be associated with either prices or energy curtailment requests. These associations needed to be pre-defined by a contract. [57], [58]
- **Profile B (OpenADR 2.0b)**
  Profile B is designed for high-end embedded devices that can support most DR services and markets. Profile B includes a flexible reporting (feedback) mechanism for past, current and future data reports. It also has the capability to provide meter telemetry. This profile is targeted at robust devices and sophisticated DR applications. Here are additional signal categories like demand charge, bid price, bid load, electricity price, etc. In 2018, the OpenADR 2.0b profile specification was also published as IEC62746-10-13 and became an international standard. In section 2.2.5 you can find more detailed information. [57], [58]

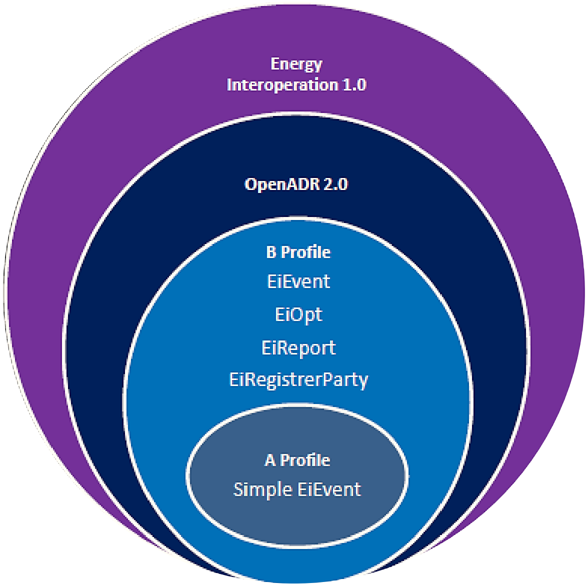


Figure 18: Two profile specifications of OpenADR 2.0, profile A & B. Source: OpenADR Alliance & QualityLogic [33]

The explanation of Event Service (EiEvent), Report Service (EiReport), etc. are described in section 2.5.4.4. It is important to mention that OpenADR 2.0 can understand the meaning of messages created with OpenADR 1.0 (= semantic backward compatibility), but the way these messages are formatted is different (= not syntactically compatible). In other words, imagine OpenADR messages as letters. Semantic backward compatibility is like being able to understand the meaning of a letter written in an older language. Even though the words and grammar are different. Syntactic compatibility is like being able to read the letter without any translation because it is written in the same language you understand. [59]

2.5.3 OpenADR Alliance

openADR ALLIANCE

Figure 19: Official logo of OpenADR Alliance. Source: OpenADR Alliance [11]

The OpenADR Alliance (Figure 19), a non-profit organization, plays a key role in promoting the adoption of OpenADR standards for smart grid communication. More specific the alliance fostered the development, adoption and compliance of OpenADR standard through collaboration, education, training, testing and certification. The alliance started to form with the development of OpenADR 2.0 in late 2010. It collaborates now with industry stakeholders or standard developing organizations to develop OpenADR implementation profiles based on the OASIS Energy Interoperation standard. The OpenADR Alliance represents the largest specialized network in the demand response field. [9], [50], [56] One of the main tasks for the OpenADR Alliance is to create a series of implementation profiles to support certification against the OASIS Energy Interoperation. It develops the conformance, certification, and testing process/program for OpenADR. A strong testing and certification program will ensure interoperability and availability of standard compliant products, easing the use of OpenADR. [9], [50], [56]

Standard implementation profiles of OpenADR will also reduce automation costs within facilities and help eliminate stranded assets. The alliance is investing substantial effort in cybersecurity. One challenge is creating different security options so OpenADR can be used in a secure way that works best for both the electricity provider and the customers. [50], [56]

Additionally, the Alliance is training and supporting system integrators, control vendors, and others to install "OpenADR-ready" equipment. They help customers to develop load management strategies and provide programs that allow vendors to develop, test, and demonstrate their ability to integrate with OpenADR signals. [50], [56]

Below there is a summary of the main goals of the OpenADR Alliance:

- Develop practical guidelines based on OASIS Energy Interoperation service descriptions.
- Guide customers in load management strategies and provide programs for vendors to develop, test, and demonstrate.
- Create a broader ecosystem of companies that offer compatible solutions for both utilities and their customers.
- Establish a testing and certification process to ensure product compatibility and minimize the need for individual testing by users.
- Create different security options so OpenADR can be used in a secure way that works best for both the customer and the utility.

2.5.4 Technical terms associated with OpenADR

In section 2.5.1 a lot of technical terms are used for explaining the working principle of OpenADR technology. In the subsections 2.5.4.1 to 2.5.4.6, these technical terms are described more in detail. Think about terms like demands response (DR), Virtual Top Node (VTN), Virtual End Node (VEN), pull and push exchange model, etc.

2.5.4.1 Demand response (DR)

The literature provides various definitions of demand response, but there is a clear common theme. [60] DR reflects electricity demand that is intentionally responsive to economic signals. Sometimes DR is confused with demand-side management (DSM), but there is a key distinction between the two. DSM can be seen as the comprehensive framework that can encompass demand response along with energy efficiency and electricity storage. [60]

Demand response involves adjusting energy consumption in response to the available energy supply by offering financial incentives to users for short-term reductions in energy demand. These adjustments are temporary decreases or increases in energy usage to support the energy system. For instance, temporal reductions can occur at times of high prices, or at times of high network loading. Temporal increases can appear at times of very low or even negative prices. Also, when there is surplus in electricity production, particularly from renewable sources. As there should always be a balance between demand and supply, the aim should be obtaining a properly sized capacity to ensure reliable power supply at affordable rates. To achieve this balance, understanding the factors influencing energy demand and to vary the demand according to the available resources are crucial. [61], [62]

In traditional power grids, balance is achieved through adjustments in supply and demand, but also by using scheduling, forecasting, and international interconnections. However, over the past few decades, concerns regarding greenhouse gas emissions and fossil fuel depletion have increased. This leaded to a transition toward renewable energy sources. Yet, renewables are stochastic, meaning their variability (like wind speed and solar irradiation) must be taken into account. This variability necessitates a more flexible grid with increased regulation capacity. DR can play a crucial role in enhancing this flexibility. [62]

Figure 20 show the different types of demand response. In practice DR is just temporary curtailment or shifting of consumption at times when it is valuable to the electricity system. Although all types of DR can be fully characterized as either load shifting or curtailment, it is also common to find “valley filling” as an extra classic form of DR. [61]

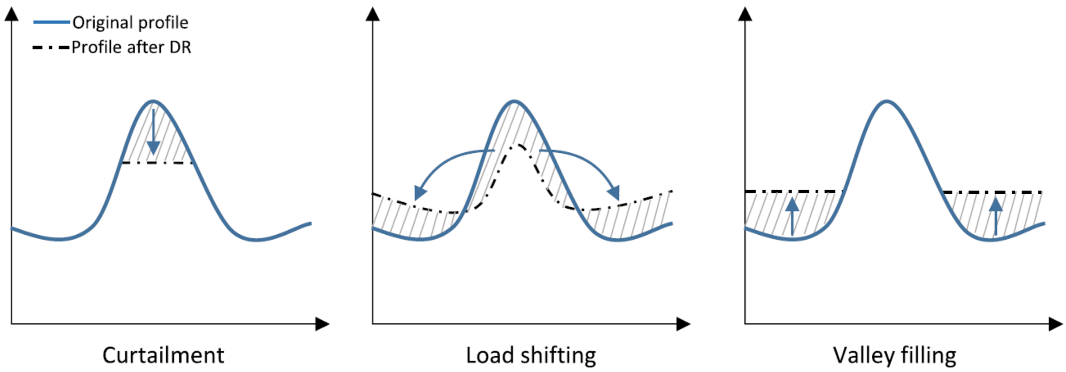


Figure 20: Different types of demand response. Source: ENERGY publication 2022 [61]

- The first type is **load curtailment or shedding**.
  This involves reducing electricity consumption during peak hours, a spike. The “profile after DR” shows a reduction in demand during this time period. Load curtailment mainly appears in two different forms: to provide capacity or to provide energy. The main difference between these two is the price that consumers are willing to pay, the former being very high and the latter being relatively low.

At *Providing Capacity* there is a shortage of generation capacity to meet peak electricity demand. Utilities are willing to pay a high price to reduce demand because a blackout would be much more expensive.

At *Providing Energy* there is enough generation capacity, but the cost of producing electricity is very high, often during peak usage times. Utilities provides a lower price to consumers to reduce their consumption and avoid buying expensive electricity at that moment. [60], [61], [62]

- The second type is **load shifting or deferral**.
  This most common DR involves shifting electricity consumption from peak hours to off-peak hours. The "profile after DR" shows a decrease in demand during peak hours and an increase in demand during off-peak hours. From the system point of view, load can "produce" energy by reducing demand when electricity prices are high and consume energy by increasing demand when prices are low. Load shifting is primarily constrained by technical limitations, as well as process requirements. The availability of unused plant capacity also plays a role. [60], [61], [62]

- The last type is **valley filling or flexible load**.
  This involves increasing electricity consumption during off-peak hours to help level out the overall demand profile. It increases the consumption levels for example at times with high renewable energy production so the demand during peak hours gets not a bigger spike. [60], [61], [62]

Several DR programs to promote responsible energy consumption and optimize grid stability can be found in [33] and [62], being the most widely implemented DR cases as follows:

- **Critical peak pricing**
  Customers get a higher rate during times of high electricity demand. This encourages customers to reduce their consumption during these peak periods. Customers may be offered lower rates during off-peak times to incentivize participation. When a peak pricing period is about to begin, a "DR Event" notification is sent to participating customers.

- **Capacity bidding**
  Companies will be notified in advance of a potential event. If an event is called, they will be asked to reduce their energy use by a certain amount for a period of time. The amount of the reduction will vary depending on the program and the severity of the event. In exchange the companies get a payment from the utility company. This helps to reduce the strain on the power grid and can help to prevent blackouts.

- **Ancillary service program**
  A program offering financial incentives to customers for reducing energy consumption during critical grid events. These events, triggered by unusual system conditions like supply shortages, impose rapid action to prevent widespread power disruptions and maintain the stability of the electrical grid.

- **Electric vehicle charging**
  The cost of charging electric vehicles adjusts to influence charging behaviour. During peak demand periods, charging costs may be higher. This motivates users to charge their vehicles during off-peak hours. "DR Events" are used to update periodically pricing information to EV charging stations. These allowing drivers to make informed decisions about when to charge based on cost. Utilities can shift load through time-based pricing incentives.

- **Direct load control**
  This concept allows the utility company to remotely adjust certain electrical equipment, like thermostats, during short-notice events. This is typically used for residential or small commercial customers. When high market prices or emergencies are anticipated, a "DR Event" is triggered which automatically adjusts the equipment for a limited time to reduce electricity usage.

Overall want consumers simplified energy management solutions with preset options and decision-making support, maintaining the ability to override automated events. For instance, an automated DR event limits electric vehicle charging before a morning commute. As a result, the vehicle is only 10% charged which could be highly disruptive. Factories commonly employ both automated and human-guided responses to fulfill requests from utilities or aggregators. [33], [61], [22]

2.5.4.2 Virtual Top Node (VTN) & Virtual End Node (VEN)

There are two actors in the OpenADR communication exchange: Virtual Top Node (VTN) & Virtual End Node (VEN). The role of a VTN is to transmit demand response events to other nodes. VTNs are the centre of interoperability for OpenADR. The role of a VEN is to receive events and to respond to them. Figure 21 clarifies the possible correlations between VTNs & VENs: [33], [50]

- A VEN typically has one VTN in a relationship.
- A VTN has one or more VENs in a relationship.
- Nevertheless, a node can be at the same time a VEN and a VTN.

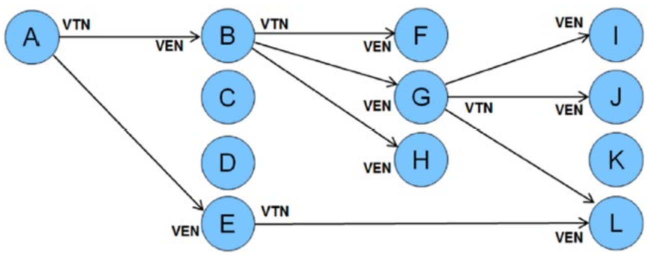


Figure 21: Correlations between VTNs & VENs. Source: OpenADR Alliance [33]

So OpenADR can essentially send signals from the utility to the aggregator, or perhaps from the aggregator down to a residential, and from a residential downstream to actual resources that shed load. The VTN is generally located at the utility side, and the VEN is part of the demand side control system. [33], [50], [63]

The VTN is the interface point of a larger system installed at the utility or an aggregator. This system is like a management server that integrates information elements from the utility control network to the downstream resources. These management servers are called Distributed Energy Resources Management System (DERMS), Demand Response Management Servers (DRMS) or Demand Side Management System (DSMS). They can be integrated into the IT structure of the utility or cloud-based. The VTN architecture (Figure 22) is divided into four modules and corresponds with the Common Information Model (CIM) from the International Electrotechnical Commission (IEC): [33], [50], [63]

- **Application Layer and Schema Validation**
  It handles the Hypertext Transfer Protocol (HTTP) services and checks the messages for compliance. HTTP facilitates the exchange of information and data between devices over the internet. [33], [50], [63]

- **OpenADR Core (OADR core)**
  This implements the OpenADR services. Additional information regarding the OpenADR service can be found in section 2.5.4.4. [33], [50], [63]

- **Memory Manager**
  The memory manager is split into two parts. The first one is a cache memory manager which stores frequently requested data in Random Access Memory (RAM). RAM is a memory to store data quickly. The second one is a persistence memory manager, which manages the connection with a relational database. The split allows the reduction of database access and increase the response times of the system. [33], [50], [63]

- **API**
  It provides an interface to other systems to use the VTN services. It is based on Representational State Transfer (REST) and JavaScript Object Notation (JSON). RESTful APIs are designed around resources, which are identified by URIs (Uniform Resource Identifiers). These resources can be manipulated using a set of predefined operations. JSON is often used as the data format for exchanging information between the client and the server due its simplicity and ease of parsing in JavaScript. [33], [50], [63]

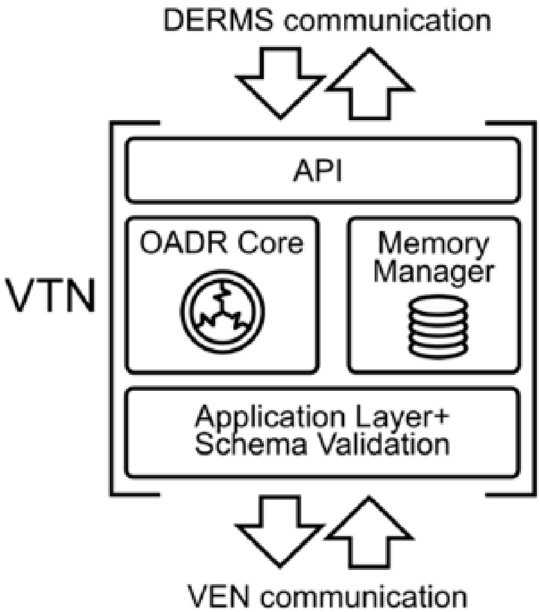


Figure 22: VTN architecture divided into four modules. Source: Sensors (Switzerland) MDPI [63]

The layer-based architecture makes the system easily upgradable to other OpenADR versions. [33], [50], [63]

The VEN is the logical counterpart of the VTN. It represents a web services client and is in general the recipient of most of the information elements. The VEN can appear in different forms. Early on these were almost always on site, so in a gateway or even directly in a control system. However, lately, the trend of cloud-based control and the Internet of Things (IoT) has shifted the OpenADR endpoint away from the resource into these cloud controllers. [33], [50], [63]

In general, the VTN is responsible for communicating the conditions and other relevant data with VENs. The VTN primarily leverages existing internet infrastructure, utilizing either broadband connections reaching buildings directly or connections routed through a centralized cloud controller. For situations where reliable connectivity is important or existing internet access is limited, dedicated connections can be established. These dedicated connections are useful for high-priority resources that require guaranteed connectivity or for systems located in areas with limited internet access.[33], [50], [63]

2.5.4.3 Two types of transports HTTP & XMPP

OpenADR is based on eXtensible Mark-up Language (XML). The language is designed for storing and transporting data. XML uses tags to define elements within a document. Users can create their own tags. This makes XML highly customizable and suitable for representing a wide range of data structures. The detailed workings of XML are not within the scope of this thesis. There are two transport mechanisms used for OpenADR communication: Simple HTTP and XMPP (Figure 23). [50], [64], [65]

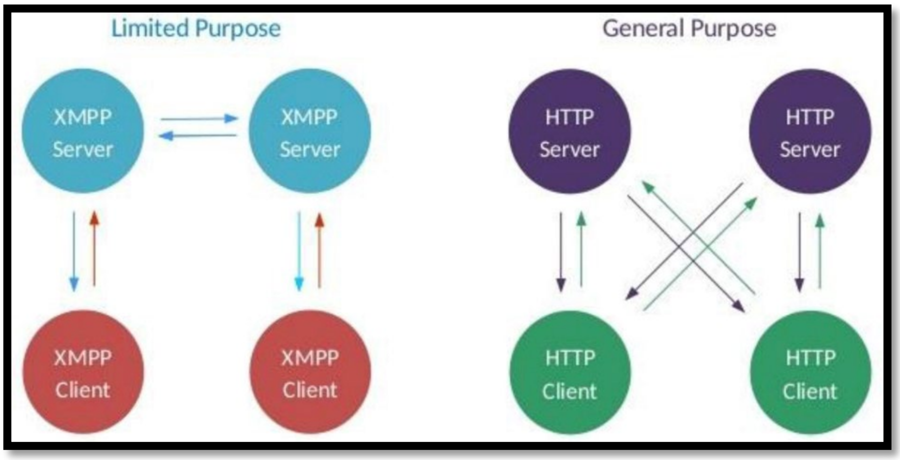


Figure 23: XMPP versus HTTP. Source: Journal of Network and Computer Applications [65]

- **eXtensible Messaging and Presence Protocol (XMPP)**
  Utilising XML, XMPP is a real-time messaging protocol and widely used for instant messaging and a presence management. A presence management system allows to determine the user's availability status, such as online, offline or busy. It uses a decentralized client-server model and secures the XML stream from spying. XMPP utilizes a Transport Layer Security (TLS) protocol. TLS is a partial protocol used to create secure channels on the Internet and works together with other protocols to encrypt data. In essence, the client encrypts a session (secret) key with the server's public key and authenticate the connection. The XMPP connections are persistent. This means that the connection between the client and server stays open, allowing for instant message delivery as soon as they are sent. As a result, latency and response times are improved but the computational requirements of the devices increases. In OpenADR, XMPP offers several advantages: [50], [64], [65], [66], [67]

  - XMPP allows *asynchronous, two-way communication* between the VTN and VEN. This implies that clients do not have to poll repetitively for status, but the service sends the results back to the client upon completion. The connection is always open. There is a constantly, persistent connection for *fast response times*.
  - XMPP integrates *robust security features* such as encryption and authentication by TLS.
  - XMPP is *decentralised* which means anyone can start a server without a central server. It also allows communication across different servers, so it is suitable for *large scaling.*

- **Hypertext Transfer Protocol (HTTP)**
  HTTP is an application layer protocol for web communication. It is also used in various fields for exchanging data. HTTP is the foundation of data communication for the World Wide Web. The communication happens in a request-response cycle. When a client sends an HTTP request to a server, it typically waits for the server to process the request and send back a response before proceeding.

OpenADR utilizes a simplified version of HTTP for data exchange in DR programs. It essentially represents a scaled down REST implementation. Key advantages of using HTTP for OpenADR include: [50], [64], [65], [66], [67]

- HTTP is *easier to implement and manage* compared to XMPP. HTTP is not secured because it does not encrypt data during client-to-server communication. Remark that HTTPS is HTTP secured with encryption and verification, using TLS.
- HTTP is *widely supported* by most devices, ensuring greater compatibility for integration with existing infrastructure.

Summarised, HTTP is commonly embraced of its simplicity and compatibility with current infrastructure. XMPP presents benefits in real-time messaging, presence detection, and scalability. Nevertheless, the vast majority of OpenADR implementations opt for HTTP usage due its simplicity. In OpenADR version 2.0 VENs can either support HTTP or XMPP, or may support both. VTNs must support both HTTP and XMPP. [50], [64], [65]

HTTP offers two exchange models: pull and push. In push mode, the VEN functions as a client and the VTN as a server. Both the VEN and the VTN can act as a client or server in push mode. So, this enables asynchronous communication without constant polling. XMPP communication is asynchronous and no polling is needed due the two-way communication. [50], [64], [65]

2.5.4.4 Messages and services according to OpenADR standard

Communication in OpenADR goes by different types of services. The OpenADR 2.0 defines four main communication services (see Figure 24) inherited from OASIS Energy Interoperation standard. A summary can be found in Table 7. [9], [50], [63], [68]

- **Event service - EiEvent** (both in OpenADR 2.0b and in OpenADR 2.0a)
  Used by the VTN to request DR operations to one or more VENs. In the OpenADR terminology, the process of requesting a DR operation is called event. Events can be accepted or rejected by the VEN. It is also used by VENs to indicate whether resources are going to participate in the event. [63], [68]
- **Registration service – EiRegisterParty** (only in OpenADR 2.0b, not in OpenADR 2.0a)
  Used to identify and enable communications between a VTN and a VEN. The key information is that the VTN provides the VEN with a unique ID. This Unique ID is used for the current communication session and the requested polling rate (push or a poll exchange model) [63], [68]
- **Report service - EiReport** (only in OpenADR 2.0b, not in OpenADR 2.0a)
  Used to share data. Both the VTN and the VEN are able to report information to each other. Resources can report their status, availability, and forecasts, but also real time energy and curtailment readings. [63], [68]

- **Opt service - EiOpt** (only in OpenADR 2.0b, not in OpenADR 2.0a)
  Used by VENs to communicate temporary availability schedule to VTNs or to qualify the resources participating in an event. For example, a VEN can communicate the period of time in which it will not accept any events coming from the VTN. [63], [68]

Additionally, OpenADR defines a fifth service the "**Poll service – oadrPoll"**, which is only used by the VEN in the HTTP pull mode to periodically poll the VTN. This is specifically important for simpler devices that cannot fully support additional messaging. [63], [68]

Table 7: Type of services. Source: OpenADR 2.0b Profile Specification [68]

Type of service	Name in OpenADR	Description	Availability in OpenADR version 2.0
Event Service	EiEvent	Send and acknowledge DR Events.	a and b
Registration service	EiRegisterParty	VEN registration, device information exchange.	b
Report service	EiReport	Request and deliver reports.	b
Opt service	EiOpt	Define temporary availability schedules.	b
Poll service	oadrPoll	Poll payloads from other services	b

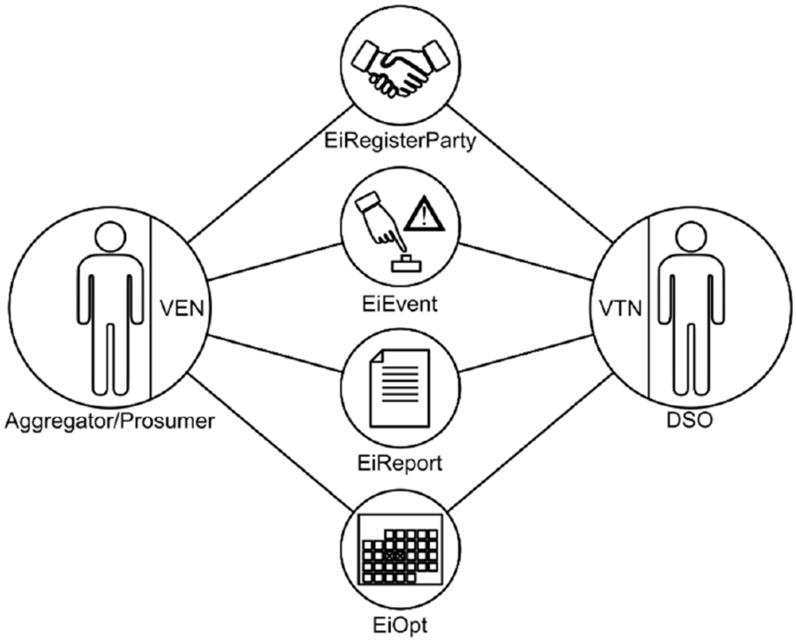


Figure 24: Main communication services. Source: Sensors (Switzerland) MDPI [63]

The heart and soul of OpenADR is the event service (EiEvent). That is the way OpenADR demand response events communicate to the VEN. There is just four simple payloads or different kinds of information that could get exchanged between the VTN and the VEN. Payloads are XML messages exchanged between VENs and VTNs. It supports logical transaction of demand response service. The typical messages can be found in Table 8. "Opt" is used to tell the VTN whether the VEN, or specific resources under the VEN, will be participating in an event. There are two ways to opt in or out of an event in OpenADR:

1. When responding to an event, include an opt in or out in the response
2. Later, using the EiOpt service

[9], [50], [63]

Table 8: Typical types of payloads. Source: OpenADR 2.0b Profile Specification [68]

Type of payload	Description
oadrRequestEvent or oadrPoll	VEN requests its DR events from VTN.
oadrDistributeEvent	VTN sends DR events to VEN.
oadrCreatedEvent	VEN tells VTN whether it will participate in the event. (optIn or optOut message)
oadrResponse	VTN acknowledges VENs. (optIn or optOut message)

2.5.4.5 Security – Cybersecurity

OpenADR incorporates security measures to safeguard the transport layer link. To provide secure two-way communications between compliant devices, the specification requires embedding X.509 v3 Public Key Infrastructure (PKI) certificates in devices at the time of manufacture. These certificates are the basis for a number of security services including authentication, confidentiality, integrity, and non-repudiation. The OpenADR Alliance itself maintains this PKI. The PKI uses server and client side digital certificates that act as digital keys to ensure only clients and servers communicate with each other and their communication is secure. [50], [69], [70]

For all message exchanges in OpenADR, use of Transport Layer Security (TLS), with client authentication is mandated for mutual authentication as well as message integrity and confidentiality protection. This protocol has version 1.2 and supports either Elliptic Curve Cryptography (ECC) and Rivest–Shamir–Adleman (RSA) ciphers. ECC and RSA are both types of key-based technique for encrypting data [50], [69], [70] An additional layer of security included in the OpenADR specification lets the user encode the actual messages that are being transported. An XML wrapper is being used to ensure that the message that was sent is also the message that is being received. This mechanism is not widely used at this time but could be deployed to avoid any instances of repudiation. Please keep in mind that communication security is continuously changing, so this thesis only offers a restricted overview. [50], [69]

Summarized:

- x.509v3 certificates for clients and servers
- TLS 1.2 with specified SHA256 ECC or RSA ciphers
- Optional XML payload signatures
- Requirements above are “out of box”, deployment security may differ

2.5.4.6 How approach certification

The primary concern of the OpenADR certification process is that the VEN is capable of responding to all of the various types of VTN requests in a manner consistent with the protocol. Therefore the requirements for the actual end device control are relatively light. In order to become certified, customer's implementations need to be able to do at minimum the following: [50], [71]

- Start control when an event starts
- End control when an event ends
- Query report data
- Asynchronous opt in/out of an event

OpenADR Alliance partnered also with a third party to create a certificate policy and to establish an OpenADR specific certificate authority. In order to obtain these certificates, manufacturers need to be compliant with the OpenADR specification and demonstrate this during the product certification process. This ensures that the basic security functions have been implemented correctly and will for instance reject incorrect security certificates among other tests. [50], [71]

Remark, the OpenADR Certification is different from the OpenADR Digital Certificate. When a VTN or a VEN gains OpenADR Certification, it indicates that the hardware has successfully completed OpenADR's testing process. So, it meets the specifications of the OpenADR interface standard. This certification process also verifies the minimum security requirements. Successfully passing these tests with completing the necessary documentation grants the status of the OpenADR Certification. However, this certification does not imply that the system is equipped with valid OpenADR Digital Certificates. [50], [71]

2.5.5 Demand response (DR) programs, OpenADR and their incentives

DR programs offer a strategy to manage electricity demand, particularly during peak periods, thus eliminating the need for new power plants. Otherwise, these new power plants are used only for a few hours during a year. These programs offer compensation to both large commercial and industrial consumers, as well as residential customers. Especially thermostatically controlled loads (freezers, heat pumps and air conditioners) are interesting for DR programs due the big share of the total energy demand and inherent thermal storage. [51], [72]

For residential customers, participation in DR programs might entail reducing air conditioning usage during peak hours. Commercial customers may implement energy efficiency enhancements in their spaces. Industrial consumers can modify production schedules, optimize equipment usage or implement energy storage. Smart technologies like thermostats, heat pumps, and energy storage systems facilitate these adjustments. Importantly, the DR programs aim to achieve these objectives without negatively impacting customer comfort or operational processes. [51], [72]

DR programs are typically operated by utilities or third-party providers. The specific program details vary, with some focusing on overall energy reduction and others on peak demand reduction. However, the shared goal is to reduce strain on the grid and promote more efficient energy use. Table 9 shows some DR programs that use or require OpenADR. For a complete list, please refer to the website[3]. [47], [51], [72]

The table focuses on load shifting incentives. Load shifting incentives reward customers for shifting their energy use away from peak times. These rewards, often paid monthly or yearly, vary based on the amount of load shifted. Customers can enroll directly or through an aggregator. The aggregator acts as a middleman to work with the end customer and connect them into the utility program. [47], [51]

Standardizing grid flexibility services with OpenADR allows providers to reduce implementation costs and complexities. It frees them to prioritize customer engagement, refine device control mechanisms, and ultimately integrate load flexibility into the energy transition. A unified communication protocol streamlines integration, makes it more efficient and cost-effective. It supports the widespread adoption of load shifting. [51], [72]

[3] https://www.gridfabric.io/oadr-programs

Table 9: Different operational demand response program in the USA. Source: GridFabric [47]

DR Program Name **[Utility]** **(Location)**	**Sector**	**Devices Targeted**	**Incentives**
Commercial DR [NV Energy] (NV)	Industrial Commercial	▪ HVAC / Thermostat ▪ Lighting Controls ▪ Building Management System ▪ Industrial Controls	▪ $25 / kW-yr bill credit, based on the customer's average kW decrease during the highest 15 DR Events (where applicable - see description). If the customer hits <50% of their target, they only receive $10 / kW-yr. ▪ Equipment rebates ▪ Covers installation cost and SaaS / platform fees that the device company charges (where applicable - see description).
Load Cooperative [Austin Energy] (TX)	Industrial Commercial	▪ HVAC / Thermostat ▪ Water Heater ▪ Lighting Controls ▪ Building Management System ▪ Industrial Controls	▪ $1.45 / kWh curtailed, up to $58,000 / year
PG&E Capacity Bidding [PG&E] (CA)	Residential Aggregator Commercial Industrial	▪ Aggregator ▪ Building Management System ▪ Lighting Controls ▪ HVAC / Thermostat ▪ Water Heater ▪ Home Energy Management ▪ Industrial Controls ▪ EV Charging	▪ $62.07 / KW - year in 2019, rates change monthly and yearly and are set by the regulator.
PowerDirect [SMUD] (CA)	Commercial Industrial	▪ Industrial Controls ▪ Building Management System ▪ HVAC / Thermostat ▪ Water Heater ▪ Lighting Controls	▪ $5 / kW / month plus 12 cents / kWh ▪ Equipment rebates ▪ $125 / kW
SCE Critical Peak Pricing [SCE] (CA)	Commercial Agricultural Industrial	▪ Lighting Controls ▪ Building Management System ▪ Industrial Controls ▪ HVAC / Thermostat	▪ Variable rate incentives: customers sign up for 12 peak pricing events per year where they pay very high rates, in exchange for lower rates the rest of the year. Exact rates depend on the customer, SCE does not publicly advertise the rates, customers can estimate how much they can save by logging into their SCE account.

3 Methodology

As discussed in the previous chapter (section 2.1), efficient and balanced operation of the electricity grid is needed to meet the increasing energy demand. The expansion of renewable energy sources (RES) requires new ways of load management. While traditional energy sources (coal, gas, nuclear, etc.) are predictable on how much electricity they will generate, RES (wind, solar, etc.) are dependent on environmental conditions. Declining fossil fuel reserves and the need to reduce CO_2 emissions are driving a shift towards RES. However, the variable and decentralized nature of RES is transforming traditional energy production and consumption patterns. Demand response (DR) aims to balance electricity demand with grid supply by incentivizing consumers to modify their usage patterns at specific times. This especially at peak times for energy demand. Figure 25 demonstrates the interaction of a simplistic DR system between utility companies and consumers to manage electricity demand during load peaks or in response to grid emergencies. [73], [74]

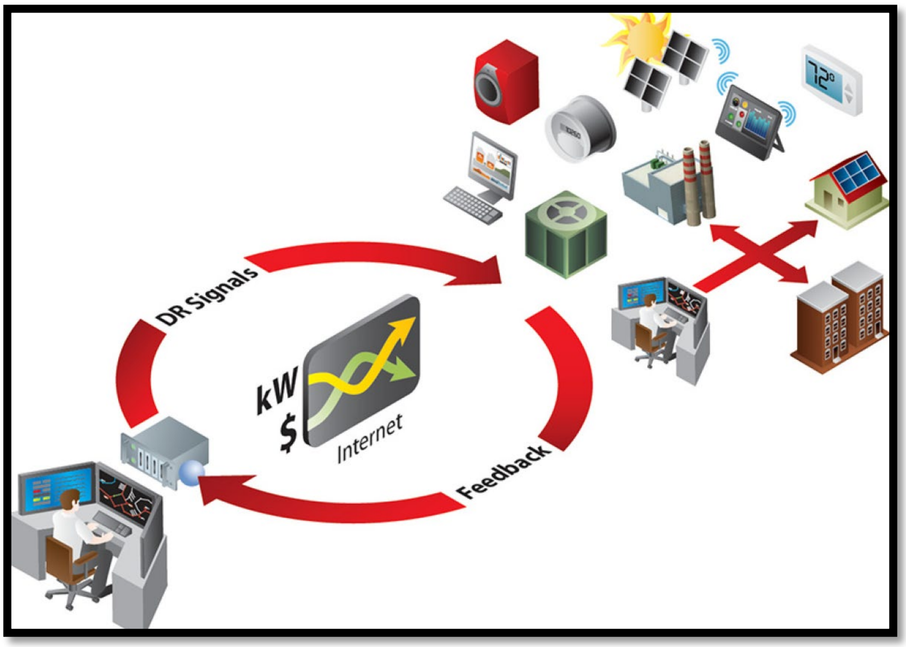


Figure 25: DR system, possible interactions between utility and consumers. Source: OpenADR Alliance [33]

The utility company sends out DR signals via the internet to various devices and systems within the consumer's premises. These signals can be price-based or event-based, indicating a need to reduce or shift electricity consumption (kW's). OpenADR, a widely adopted communication protocol, is used to transmit and secure the DR signals. Consumers' devices and systems send feedback data on their electricity usage back to the utility company. This data allows the utility company to monitor the effectiveness of the DR program and make necessary adjustments. [75]

3.1 Identification

This identification highlights the key problem that this thesis seeks to investigate namely the general design, implementation and validation for aggregating demand response resources using OpenADR. Implementing DR leads to a variety of DR programs, players, and approaches that require assessment and evaluation from economic and technical perspectives. Also, an environmental evaluation will be applied.

The methodology (Figure 26) starts with establishing an agreement between an aggregator and the consumer. If not, a flexibility audit is performed for validating possible DR actions and cost effectiveness. The aggregator has already installed OpenADR hardware for communicating with consumers. The next step is to check if there is OpenADR hardware and telemetry available at the consumer side for being able to participate DR. Now is the consumer ready and is waiting for perform a DR action from the energy system at the utility side.

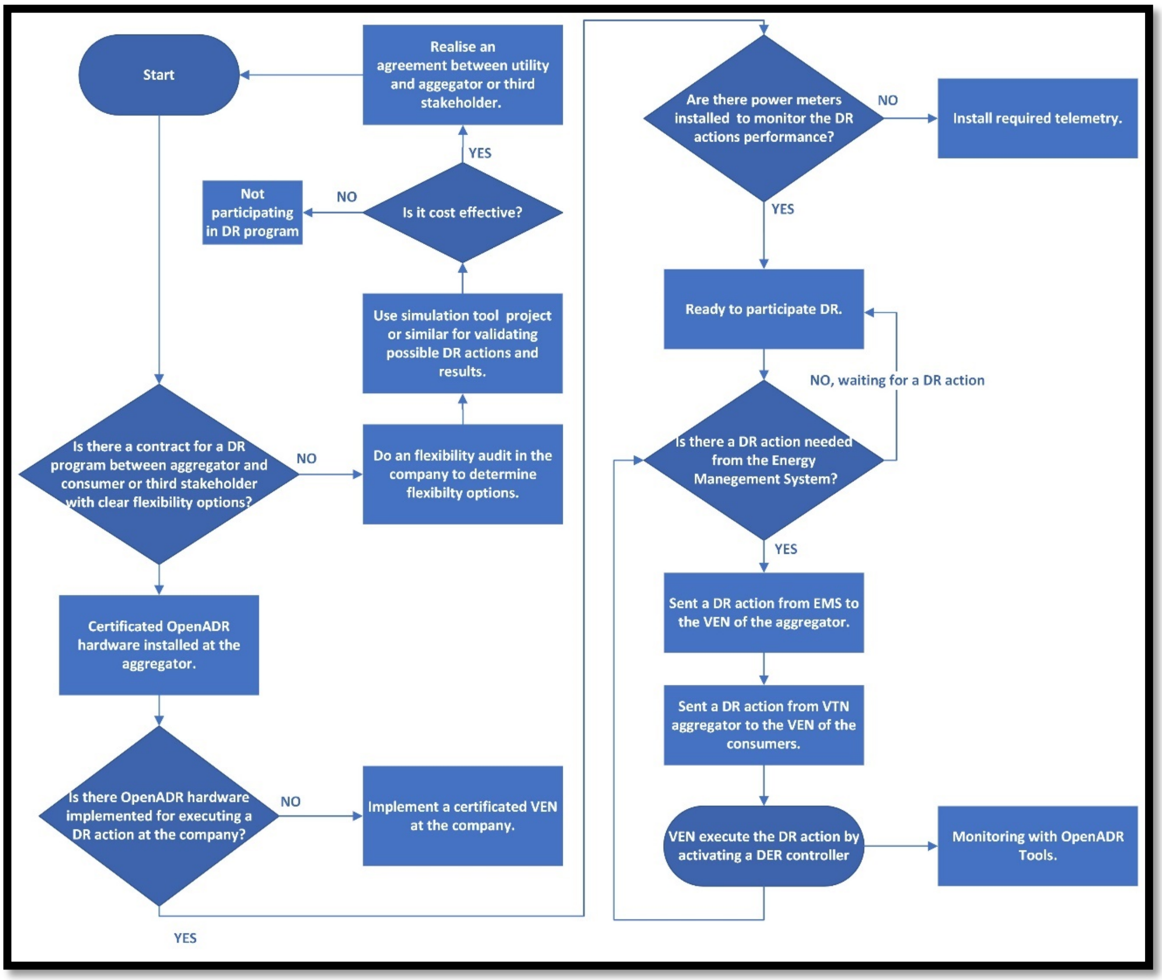


Figure 26: Flow chart of the methodology. Source: own elaboration

3.2 Design architecture for the aggregation with OpenADR

Figure 27 gives a general overview for aggregation with demand response using OpenADR.

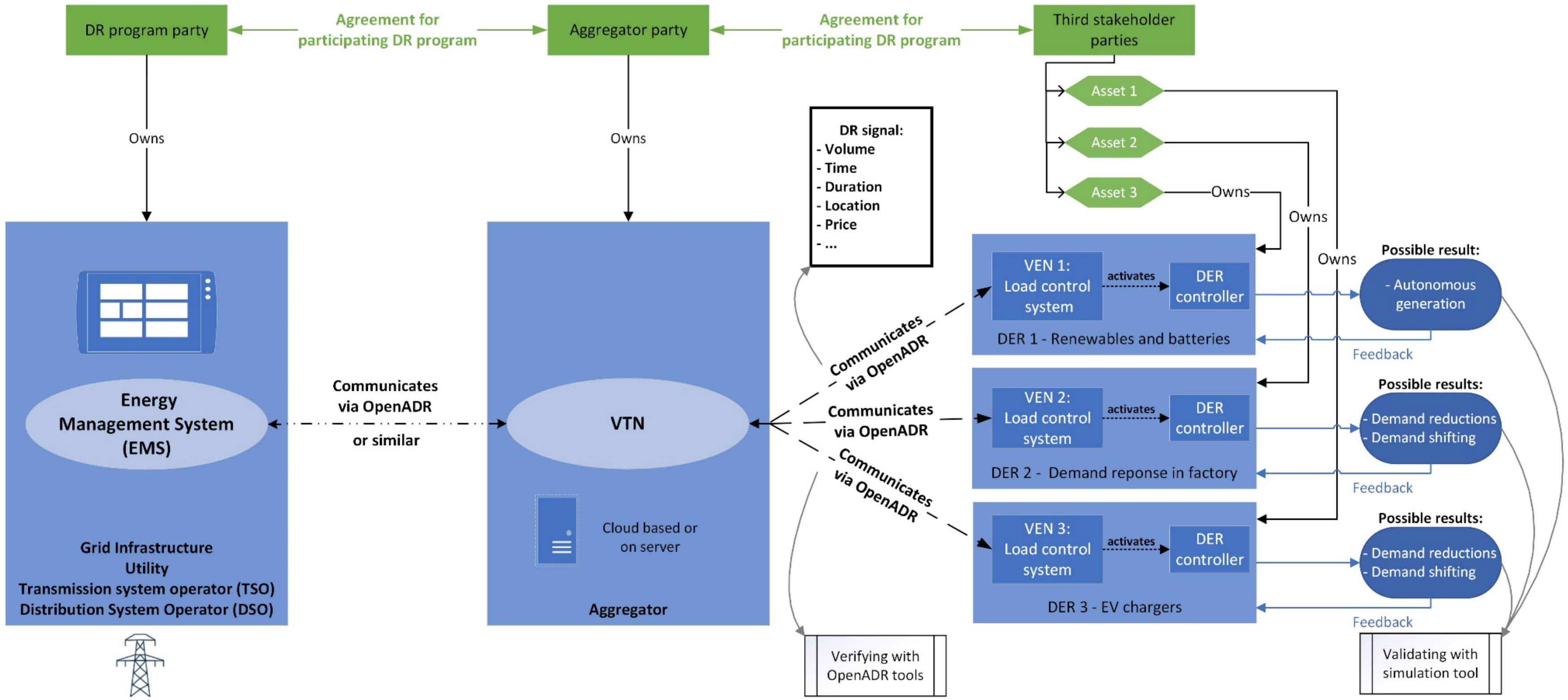


Figure 27: General overview for aggregation with demand response using OpenADR. Source: Own elaboration

The Energy Management system (EMS) of the grid structure communicates with the VTN of the aggregator for activating a demand response program. This can be the OpenADR protocol, as the architecture diagram on Figure 13 in section 2.2.9.2 is shown, or a similar protocol what demand responses support. The aggregator uses a VTN to execute the DR and communicate it back to the utility. The VTN can be cloud-based or installed on location. Each distributed energy resource (DER) has a VEN which is connected to a controller for reducing or shifting loads.

The DR program party and the aggregator party establish an agreement for participation in the DR program. Eventually, there can be also an agreement with third stakeholders. The energy provider transmits a signal from the EMS to the aggregator for a possible DR program. The VTN on the aggregator level checks the availability and if possible, execute a DR program to the VEN. Communication happens in DR signals. The DR signal is defined by the OpenADR protocol and can include information on the required volume, time, duration, location, or price. The DER controller activates the load control system. The activation of the controller can happen in another protocol then OpenADR like DNP3, OCPP, etc. Possible responses include load reduction, load shifting or autonomous generation. Each DR program party sends feedback data to the VTN regarding their actual response to the DR signal. The feedback helps to validate the demand response program. Note that the diagram indicates that communication between entities primarily happens through the OpenADR protocol, but similar protocols can be used.

A typical grid structure in Europe is shown on Figure 28. A Transmission System Operator (TSO) manages the transfer of electricity across high-voltage power grids, typically operating between 220 kV and 380 kV in Europe. They connect large power plants (usually exceeding 100 MW) to regional or local distributors, ensuring efficient and reliable power delivery. One of the key responsibilities of TSOs is to procure ancillary services to guarantee system security. Demand response programs can be a valuable tool in achieving this goal. [76]

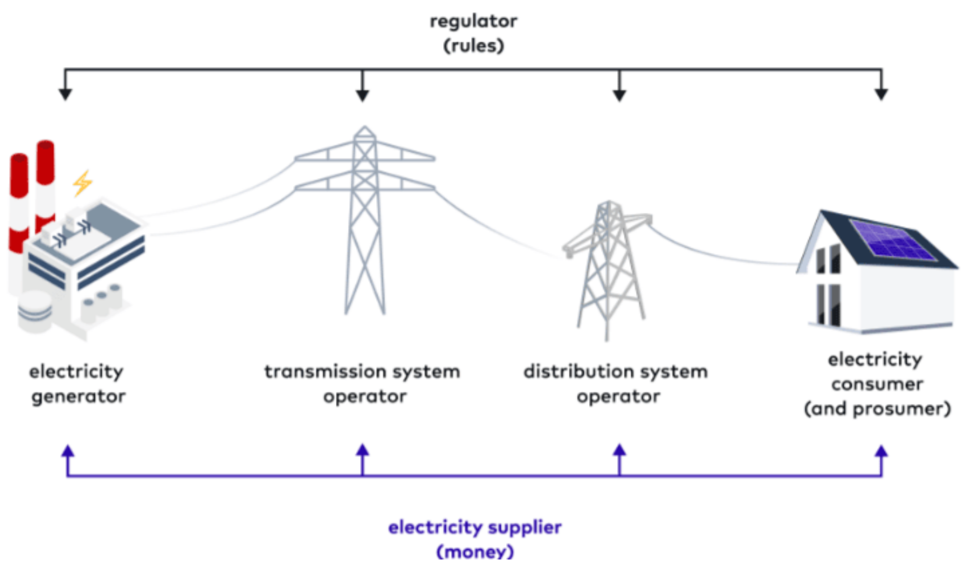


Figure 28: Typical grid structure in Europe. Source: gridX [76]

Distribution System Operators (DSOs) are in authority for the local and regional electrical infrastructure that delivers power directly to consumers. This infrastructure consists low voltage (250-400 V) and medium voltage (6-50 kV) networks. With the increasing integration of DERs into the grid, DSOs face new challenges, such as managing peak demand and preventing network overload. To address these issues, DSOs may utilize demand response programs as a tool. So, depending on the situation and which country, the DSO can also activate demand response programs instead of the TSO. [72], [76]

Effective communication and information sharing between TSOs and DSOs is essential for maintaining a high-performing power grid with a large number of DERs. TSOs and DSOs can then more effectively pinpoint areas of concern and identify opportunities for collaboration among interconnected entities to address the demands of the power grid. An energy management system (EMS) functions as a data exchange platform for gathering the necessary information and transferring this to the right locations. Figure 29 shows some typical inputs and end users who use the gathered information. The EMS is a set of tools combining software and hardware that optimally distributes energy flows between connected DERs. This central data hub collects, analyses and visualizes data in real time and dynamically controls energy flows. It can be centralized or distributed. The location of DR logic events, and the decisions regarding when an event is needed and how to respond, can vary. In a previous chapter, Figure 17 in section 2.5.1 illustrated these different possibilities. In the general overview shown in Figure 27 the DR logic can be located either in EMS of the utility or at the gateway of the aggregator. The location depends on how easy the technique is to integrate. [50], [72], [76], [77]

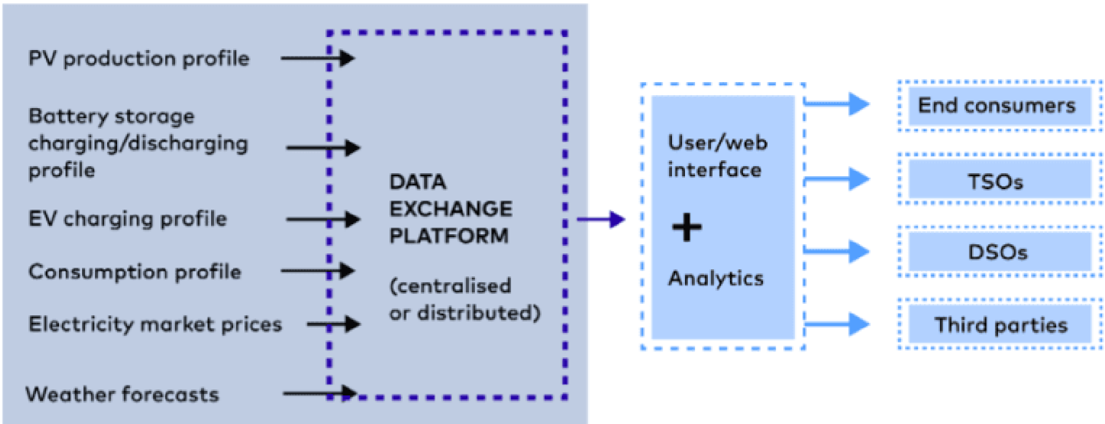


Figure 29: An EMS act as a data exchange platform. Source: gridX [76]

The design architecture utilizes an aggregator to activate a DR program, control signals and sent to the load control system, and gather status and measurement data. There are a lot of different types of DR programs. An overview can be found in Figure 30. Figure 30 specifies more the incentive-based and price-based DR. Below is a description of the various types:

- **Price-based DR**: In this type of program, the price of electricity varies over time. This incentivizes users to shift their energy usage to times when electricity is cheaper.
  1 **Real-time pricing**: Electricity prices change hourly based on the wholesale market price. This gives consumers the most flexibility but also requires them to actively monitor prices.
  2 **Extreme day pricing**: Similar to time-of-use pricing, but with higher price differentials between peak and off-peak periods. This provides a stronger incentive for load shifting but may be less appealing to some consumers.
  3 **Time of use pricing**: The day is divided into periods with different predetermined prices. This is the simplest and most common form of dynamic pricing, but it offers limited flexibility due to typically small price differences between peak and off-peak periods.
  4 **Critical peak pricing**: Similar to ToU, but with an additional "critical peak period" with very high prices. This is designed to reduce demand during periods of extreme stress on the grid. Consumers are typically notified in advance of a critical peak period.

  [72], [78]

- **Incentive-based DR**: This type of program offers users direct financial incentives, such as discounts or rebates, for reducing their energy usage during peak times.

  ↳ **Direct Control**: The utility or program administrator can remotely control specific devices to reduce load during peak times. This could include turning off air conditioners or water heaters for short periods.
  1 **Direct Load Control**: The utility can remotely control specific devices, such as air conditioners or water heaters, to reduce load during peak times.
  2 **Interruptible Load**: Customers are paid to allow the utility to interrupt their power for short periods during peak demand. This is typically used for large industrial or commercial customers.

  [72], [78]

  ↳ **Indirect Control**: Customers are incentivized to reduce their electricity usage through programs that reward them for doing so. It is market based.
  1 **Emergency Demand Response**: Customers are asked to reduce their electricity usage during emergencies, such as power outages or extreme weather events.
  2 **Demand Bidding**: Customers can bid into a market to be paid for reducing their electricity usage during peak times.
  3 **Capacity Market Programs**: Customers are paid to reduce their electricity usage during peak times to help ensure that there is enough capacity to meet demand.
  4 **Ancillary Services Market Programs**: Customers are paid to provide services to the grid, such as frequency regulation or voltage support.

  [72], [78]

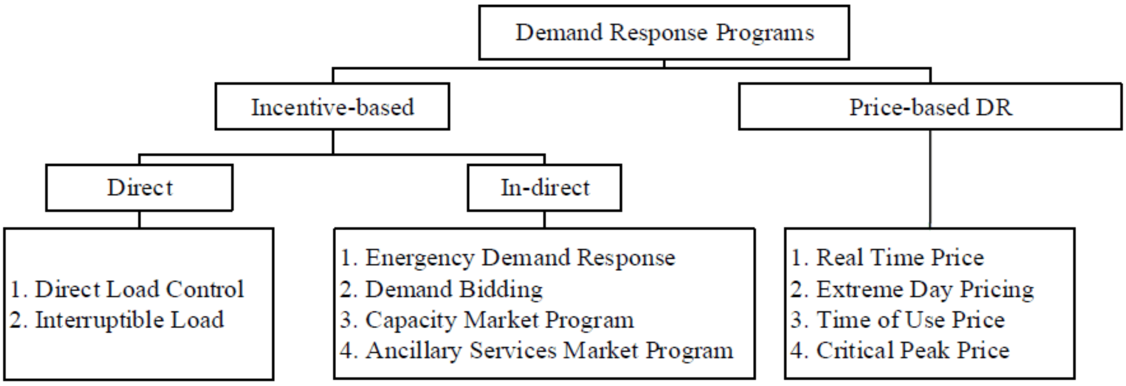


Figure 30: Overview of DR programs, focus on incentive-base and price-based DR [72]

Some DR types are defined by a notification time. Table 10 gives typical notification times. The notification time refers to how far in advance participants in a DR program are notified of an event that requires them to adjust their electricity usage.

Table 10: Typical notification time for DR types. Source: MDPI [72]

DR type	**Notification time**
Direct load control	1-60 s
Interruptible load	1-60 s
Emergency demand response	1800-7200 s (60-120 min.)
Capacity market program	1800-7200 s (60-120 min.)
Ancillary services market program	1800-7200 s (60-120 min.)

Note that ancillary services (AS) are divided into different categories for a tiered response to frequency deviations. This ensures that the grid remains stable and reliable even in the face of sudden fluctuations in electricity generation or demand. Systems use different nomenclature for AS across the world. The following paragraph focuses on the standards for AS by European Network of Transmission System Operators for Electricity (ENTSO-E). It is European best-known standard and represents 42 TSOs from 35 European countries. (Figure 31) Among its various roles, ENTSO-E coordinates the majority of European TSOs and shared common network codes for the countries. ENTSO-E's terminology for frequency control services are: [79], [80]

1/ **Frequency Containment Reserve (FCR)** or **Primary Reserve**
This automatic service stabilizes frequency following minor, unexpected imbalances. It activates within 30 seconds of an imbalance and operates for up to 15 minutes.

2/ **Frequency Restoration Reserve (FRR)**
This service addresses imbalances too large or prolonged for FCR to handle, aiming to restore frequency and take over from FCR. Two types of FRR exist:

2a/ **Automatic Frequency Restoration Reserve (aFRR)** or **Secondary Reserve**
It operates between 30 seconds and 15 minutes after frequency deviation.
2b/ **Manual Frequency Restoration Reserve (mFRR)** or **Tertiary Reserve**
It relies on manual intervention and activates within 15 minutes of the imbalance.

3/ **Replacement Reserve (RR)**

This is a supplementary reserve. RR is manually activated to complement or replace FRR when needed. It is triggered no earlier than 15 minutes following a frequency deviation.

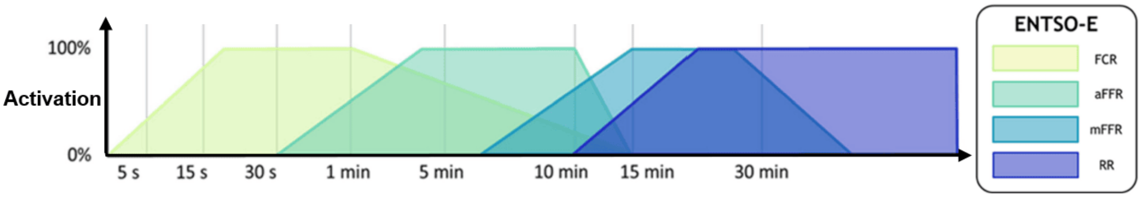


Figure 31: Nomenclature from ENTSO-E for ancillary services. Source: ENTSO-E [79]

3.3 Requirements for interchange of DR resources

This section details the technical requirements for implementing the design architecture presented in section 3.2, Figure 27. As a start, the following general hardware and software requirements for installing the proper interchange of DR resources are given so the reader has a good global overview. [81]

The **hardware** requirements: [81]

- Load operation: the ability to control and manage electrical loads.
- Secure data storage.
  - ➔ Ensure the database server is physically secured within a restricted-access data centre and back up the database to a secure offsite location.
- The capacity to communicate and exchange data among various stakeholders (utilities, system operators, aggregators, consumers, etc.) This requires sufficient bandwidth and accuracy.
  - ➔ OpenADR hardware is used in this methodology. (Figure 32 and Figure 33)
- The functionality to measure and register essential variables such as electrical parameters, event timestamps, event counters, and other relevant data for baseline assessment (solar radiation, temperatures, etc.).
  - ➔ Install smart meters or advanced metering infrastructure so the described parameters above are measured.
- To ensure system reliability, the hardware should include redundancy features or mechanisms for backup and restoration in case of failures.
  - ➔ Regularly test failover procedures to ensure seamless switchover in case of a primary system failure.
  - ➔ Consider cloud-based backup solutions for additional redundancy and disaster recovery.

The **software** requirements: [81]

- Tools for coordinating and managing DR events in real time.
- Software for secure storage and management of information within the database.
- Software that enables communication among different entities, ideally utilizing a standardized communication protocol.
  - ➔ OpenADR is used in this methodology.
- Software for managing and processing measurement data from sensors and meters.
- Software tools for facilitating negotiations between resource providers and DR resource consumer like auctions (bids and offers), bilateral or multilateral negotiations.
- Software for analysis of DR data and for evaluating DR program effectiveness.
  - ➔ For validating and verifying results the evaluation developed during the Demand Response in Industrial Production project is applied in this methodology. Further details are available in section 3.5.
- Tools for settlement to automate financial settlements between demand response participants, ensuring accurate and timely payments based on agreed-upon terms.

Some general described requirements are out of the scope of this thesis. The following steps focuses for the requirements for implementing the design architecture presented in section 3.2, Figure 27:

1 A majority of consumers are uninformed about their energy usage patterns. An audit is essential to assess the electrical usage of various processes and to identify the DR actions that can be applied in industrial facilities. The audit is used for analysing the energy consumption profile and the possible flexibilities in their industrial production processes. Some hardware in the factory needs to be installed like smart telemetry and a gateway for internet access gathering and monitoring online data. These data are typical load curves from different industrial processes and the total load curve. Economical, technical, and environmental evaluations are crucial for providing accurate recommendations. The audit follows the DRIP approach for these evaluations, further detailed in section 3.5. A summary of how these evaluations work is as follows:

   a. Section 3.5.1 describes in detail the technical evaluation. In summary a calculated baseline is used for the load curve without DR comparing with the load curve with an executed DR.

      In this section is also typical days defined, description of technical parameters when a DR is active and flexibility actions explained.

      The energy balance (EB_{Total}) involved in the DR process in the month is calculated as the difference between the energy reduces during the DR events (E_1) and the additional energy consumed before and after these DR events (E_2 and E_3 respectively):

$$EB_{TOTAL} = E_1 - (E_2 + E_3) = \sum_{h=1}^{p} E_1^h - \left[\sum_{h=1}^{p} E_2^h + \sum_{h=1}^{p} E_3^h\right] \quad (1.1)$$

where h is the number of the DR event and p is the total number of DR events in the month.

b. Section 3.5.2 describes in detail the economical evaluation. In summary a margin of decision (M_D) is performed. If $M_D = B_R - B_{NE} > 0$, the customer provides a DR with economic advantages. B_{NE} is the expected benefit for the customer.

In order to calculate the real benefit (B_R), it is necessary to assess a set of parameters in advance such as the economic balance (S_S), the benefit of the extension of machinery useful life (S_{MA}), the payment offered by the TSO in the reserve energy market (P_M) and the variable costs (C_{VAR}):

$$B_R = S_S + S_{MA} + P_M - C_{VAR} \quad (1.2)$$

In conclusion profitable for the customer if:

$$P_M > C_{VAR} + B_{NE} - S_S - S_{MA} \quad (1.3)$$

See also Figure 57 in section 3.5.2.2 for clarification.

c. Section 3.5.3 describes in detail the environmental evaluation. In summary the environmental impact of all the DR events associated with all the DR processes in the month is calculated as the CO_2 emission balance (CE_{TOTAL}) between the avoided CO_2 (CE_1) and the extra CO_2 emitted to the atmosphere due to the extra electrical consumption before and after all the DR events (CE_2 and CE_3):

$$CE_{TOTAL} = CE_1 - (CE_2 + CE_3) = \sum_{k=1}^{n} E_1^k \cdot f_k - \left[\sum_{k=1}^{n} E_2^k \cdot f_k + \sum_{k=1}^{n} E_3^k \cdot f_k\right] \quad (1.4)$$

where k is associated with the time period of each different CO_2 emission factor (i.e. CO_2 emission factor of on-peak, shoulder and valley periods.)

2 If the audit is promising ($M_D > 0$), agreement for DR program can be negotiated between utility and consumer. This agreement outlines the terms and conditions of participation, including incentives, response requirements, etc.

3 OpenADR hardware setup for demand response can be installed.
   a. The VTN can be installed on a local server at the utility/aggregator side or cloud-based. The VTN is responsible for managing DR events and communicating with the VEN
   b. The VEN acts as an intermediary device, receiving DR signals from the VTN and activating the DER controller at the facility side.

   Note that these OpenADR hardware has special certification. See section 2.5.4.6. As described in section 2.5.4.2, the relationship for a VTN to a VEN is one to many. Each VEN only connects to one VTN. Other background information about OpenADR can be found in section 2.5.

4 Implementing software for communication between VTN and VEN using the OpenADR protocol. This software handles tasks such as verifying DR signals, creating and managing DR events, and ensuring secure and reliable communication. See section 3.4 for more information for OpenADR tools. These OpenADR tools include:
   a. Event flow
   b. Snapback after a DR event
   c. Verifying the DR response signals
   d. Creating events

   Signals are the event content: they describe the VTN's request to the VEN (for example initiate control level of 2, please provide 10 kW, etc.). Events may include one or many signals in parallel (the diagram describes an event with 2 signals). In section 3.4.1, there is more information about the event flow. [82]

5 Participate in a DR program. Once the hardware and software are in place, the facility can actively participate in the DR program. This involves responding to DR signals from the VTN, adjusting energy usage as requested, and reporting back on the DR actions taken.

3.4 Platforms of OpenADR

Organizations managing load-consuming devices must define their response to OpenADR signals. This involves: [71]

- Evaluating the financial benefits of participating in OpenADR programs and how to control their devices for capturing value.
- Obtaining consent from device owners (building managers, homeowners, …) for load control.
- Integrating OpenADR into their existing device control systems.

OpenADR platforms can address the last item mentioned above, the integration challenge. These platforms act as intermediaries between the OpenADR protocol and various device control systems. The OpenADR protocol offers extensive capabilities for managing diverse programs, but its flexibility introduces complexity. OpenADR platforms typically implement only the necessary components of the protocol for specific utility programs, simplifying integration and usage.

So, platforms of OpenADR are used for integration and implementing the communication protocol in a convenient way. There are some companies providing this integration of OpenADR. Most significants are:

- **GridFabric** [83]
- **GRIDlink Technologies** [84]
- **AutoGrid** [85]

This thesis investigates the potential of GRIDlink Technologies platforms, a brand name under IC Systems. IC Systems is a US-based private engineering company specializing in demand response, energy monitoring, cloud data acquisition, solar tracking and field networking. The OpenADR platforms work together with hardware that is certified. In the e-SYM lab is GRIDlink series 113 used for working together with the OpenADR platforms. (Figure 32 and Figure 33) The general possibilities of these platforms for applying a demand response are described in this chapter. Some functions can be applied across different platforms because the OpenADR Alliance has standardized certain features. [84]

As discussed in section 2.5.4.4, OpenADR in general the next things: [71]

- Registration: This is the registration process involves a VEN securely registering with a VTN.
- Events: This allows the VTN to communicate upcoming load shifting requirements and market conditions to the VEN.
- Opts: This indicating the participation in a specific event for a VEN.
  Opt in: participate in an event
  Opt out: participate not in an event
- Reports: This is used ongoing communication of metrics such as device status or energy usage

Figure 32: OpenADR hardware, GRIDlink series 113 front side. Available at the e-SYM lab. Source: Own elaboration.

Figure 33: OpenADR hardware, GRIDlink series 113 inputs and outputs possibilities. Available at the e-SYM lab. Source: Own elaboration.

Figure 34 illustrates an overview of GRIDlink Technologies system to manage and control DERs utilizing the OpenADR protocol. Key functionalities include:

- Direct device control for utilities at the user level
- Instant streaming of user-defined data, including meter interval data, to a secure historian via API
- Custom software development to ensure seamless interoperability
- Remote software and configuration upgrades for continuous platform operation
- Robust cybersecurity measures for both online and local network protection

[86]

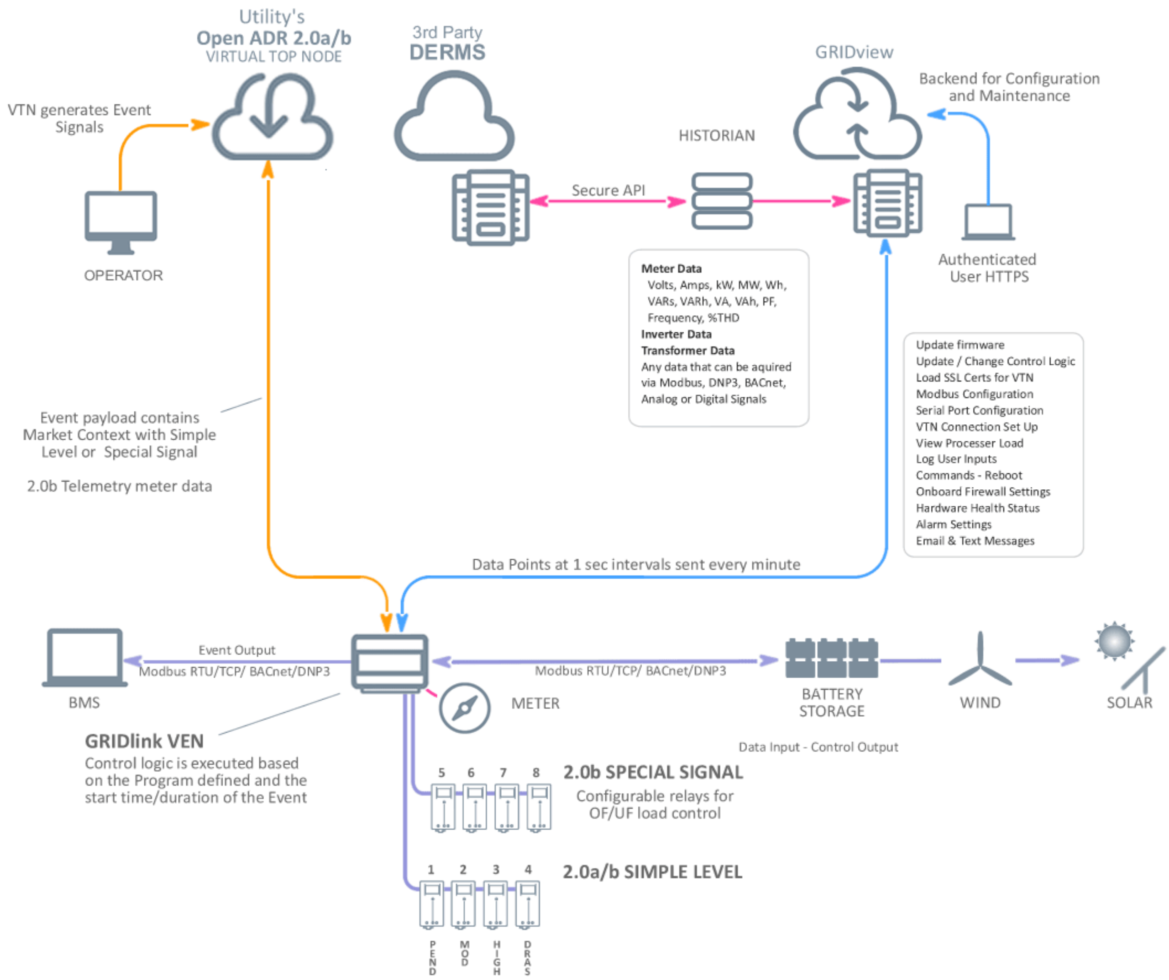


Figure 34: Overview of GRIDlink Technologies system to manage and control DERs. Source: GRIDlink Technologies [86]

3.4.1 Event flow

An event is one of the important parts on how OpenADR communicates. The typical payloads or XML messages exchanged between the VTN and VEN were described in section 2.5.4.3. This section shows how events propagate through the OpenADR platform. (Figure 35)

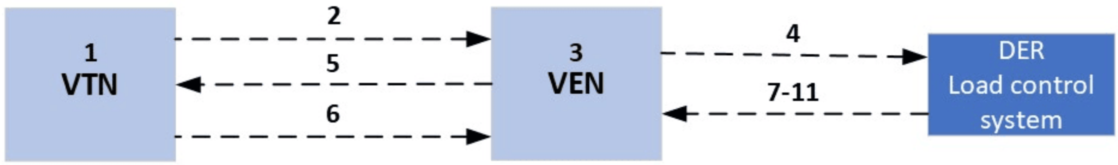


Figure 35: Event flow. Source: Own elaboration based on GridFabric [82]

The following steps in an event flow is a typical scenario in an OpenADR system: [82]

1. VTN creates a new event.
2. VTN creates an oadrDistributeEvent and sends to VEN on the next poll.
3. The VEN logs that a new event is processing and posts event parameters. It also continues to log ongoing event activities.
4. The VEN triggers a DistributeEvent function to start with all events. It includes all events sent by the VTN to the VEN. This may include past events, current events, active events, etc.
5. The VEN responds to the VTN with oadrCreatedEvent.
6. VTN acknowledges the created event with an oadrResponse.
7. The VEN triggers an Event function for each event sent by the VTN. (and cancelEvent for each cancelled event sent by VTN)
8. The VEN triggers a DistributeEvent function for giving feedback as complete. It is used to inform the system that no more events and cancelled events messages are coming.
9. When event start time comes, the VEN triggers an event to start and the the first EventInterval functions activates. It includes information about the interval (duration, payload and signal type, …). The first interval will start at the same time as the event starts.
10. If there are more intervals, the VEN will continue to trigger EventInterval function when the next interval starts.
11. When the event is over, the VEN triggers an endEvent function as feedback.

For a full understanding of the specific terms like DistributeEvent, oadrCreatedEvent, etc. see OpenADR 2.0b Profile Specification. [68]

3.4.2 Snapback after a DR Event

Figure 56, section 3.5.1, shows the reduced supply in a DR is reactivated once the interruption ends. This results in an additional consumption E3 required to restore the original settings. In the OpenADR platform it is called "snapback after a DR event". The next section describes a possibility to improve an overall energy saving.

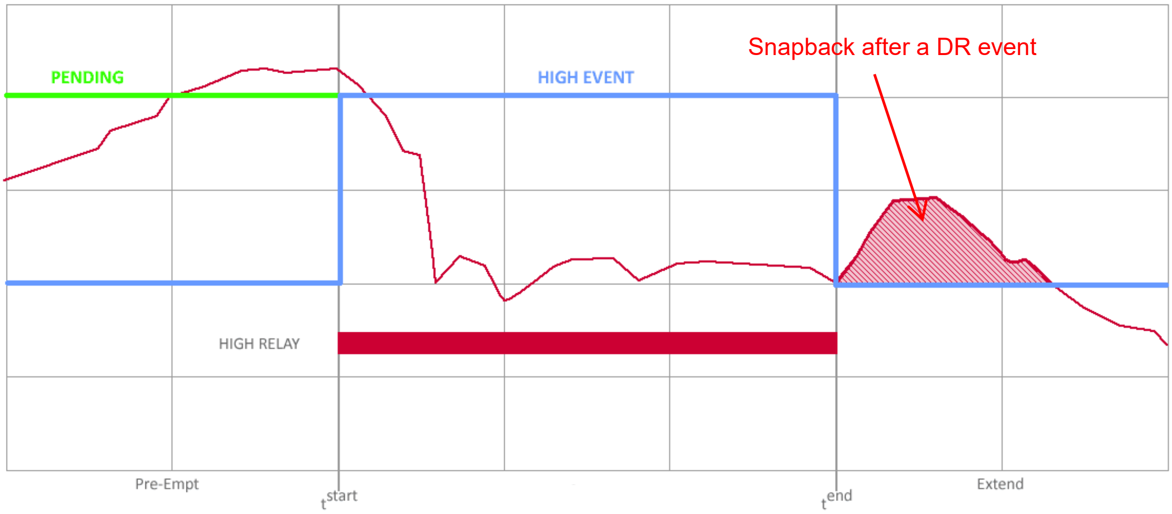


Figure 36: Demand response snapback. Source: GRIDlink Technologies [87]

DR events are basically binary control (ON-OFF). The MODERATE or HIGH signal choice does give the utility some granularity to attain the curtailment necessary but what is the effect at the customer level when equipment begins to rebound back to normal operation? [87]

Some VENs utilize the OpenADR ramp settings to allow the Output to start before the Event start time and end minutes after the Event end time. The fundamental problem is still the single binary output. There is no way to divide the load into individual resources without expensive re-programming of the EMS much less the rotating equipment. [87]

As a solution the VEN hardware from GRIDlink offers:

- Additional binary outputs that follow the Moderate or High signals.
- Individually configurable Start and End times from minutes to several hours.

Results will depend on the type of equipment and demand profile.

Figure 37 illustrates how by using the Pending Relay to Pre-Empt the Event and consume energy and then stagger the recovery over multiple loads can smooth the snapback. This is achieved by simple configuration without any programming required. [87]

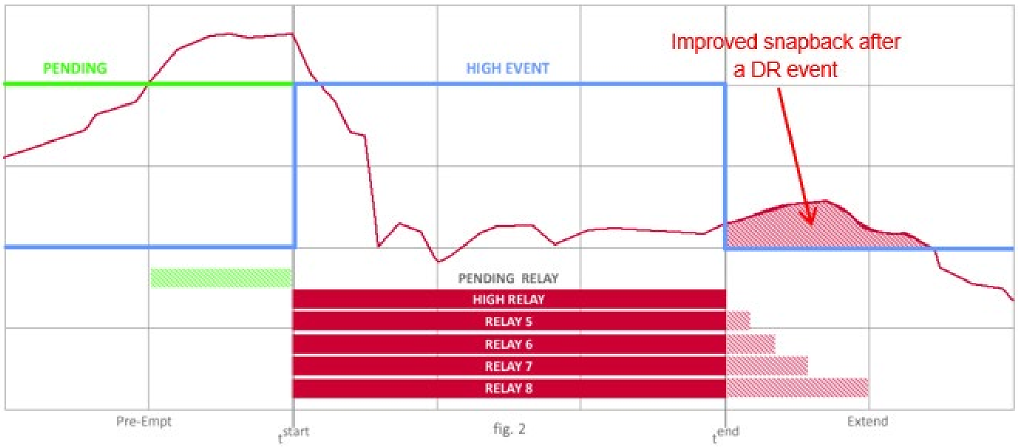


Figure 37: Demand response snapback, improved energy saving. Source: GRIDlink Technologies [87]

3.4.3 Event "Ride Through"

GRIDlink devices are engineered to withstand internet outages during an event. A built-in feature called "Ride Through" ensures safety and reliability. When an event notification is successfully received before an internet connection is lost, the OpenADR software captures and stores the event details. This process only needs one successful parse. From this point, GRIDlink can execute the event without an active internet connection. [88]

The only visible indicator of an internet outage is the DO4 LED turning off, which will turn back on once the connection is restored. It's important to note that intermittent changes in the DO4 status are not uncommon and do not necessarily indicate an issue. Due to the "Ride Through" functionality, the event will end as planned, preventing unnecessary relay cycling that could potentially harm equipment or machinery. [88]

In cases of power outages, relays may drop out regardless of the internet connection status. When power is restored, the relays will re-energize if an event was in progress. This can disrupt operations, so it's recommended to use an Uninterruptible Power Supply (UPS) in environments with unreliable power. [88]

3.4.4 Virtual Top Node (VTN)

As described in section 2.5.4.2, a VTN can be a local server or cloud based. The chosen VTN is a server based VTN, developed by the Electric Power Research Institute (EPRI) and delivered by GRIDlink Technologies. EPRI has made available a fully functional, open-source software implementation of both the VEN and VTN components. It is a scientific organization dedicated to advancing energy solutions for a sustainable future. EPRI delivers independent, objective thought leadership and industry expertise through a highly collaborative approach. There are two websites used for controlling the VTN, as shown in Table 11. A full manual for these online platforms are out of the scope of this thesis, but the most important functions can be found in this chapter. [89]

Table 11: Overview of the used websites. Source: Own elaboration

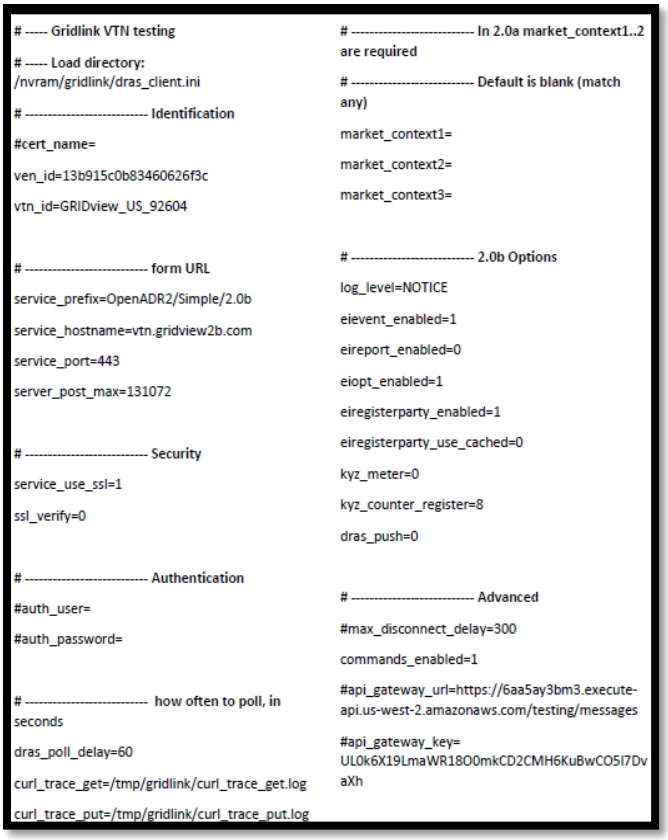
Name of the platform	Website	Description
GRIDview2b	https://vtn.gridview2b.com	Used for creating events, making targets, configurating the VTN, testing, etc.
GRIDview NA	https://na.gridview.technology/	Universal user interface for controlling GRIDlink hardware.

3.4.4.1 GRIDview2b

GRIDview2b (https://vtn.gridview2b.com) is used for managing and optimizing energy demand response system. It facilitates the creation of events, establishment of targets, configuration of the VTN, the testing of case prompts and the creation of schedules. As earlier mentioned, this thesis is not a manual for the OpenADR platforms. Refer to the official website for full guidelines and the possibilities.

3.4.4.1.1 Configure the VTN

With administrator privileges the user can make the connection to VTN by modifying a text file "dras_client.ini". The description of these settings can be found in Appendix 3.



```
# ----- Gridlink VTN testing
# ----- Load directory:
/nvram/gridlink/dras_client.ini
# -------------------------- Identification
#cert_name=
ven_id=13b915c0b83460626f3c
vtn_id=GRIDview_US_92604

# -------------------------- form URL
service_prefix=OpenADR2/Simple/2.0b
service_hostname=vtn.gridview2b.com
service_port=443
server_post_max=131072

# -------------------------- Security
service_use_ssl=1
ssl_verify=0

# -------------------------- Authentication
#auth_user=
#auth_password=

# --------------------------  how often to poll, in
seconds
dras_poll_delay=60
curl_trace_get=/tmp/gridlink/curl_trace_get.log
curl_trace_put=/tmp/gridlink/curl_trace_put.log

# -------------------------- In 2.0a market_context1..2
are required
# -------------------------- Default is blank (match
any)
market_context1=
market_context2=
market_context3=

# -------------------------- 2.0b Options
log_level=NOTICE
eievent_enabled=1
eireport_enabled=0
eiopt_enabled=1
eiregisterparty_enabled=1
eiregisterparty_use_cached=0
kyz_meter=0
kyz_counter_register=8
dras_push=0

# -------------------------- Advanced
#max_disconnect_delay=300
commands_enabled=1
#api_gateway_url=https://6aa5ay3bm3.execute-
api.us-west-2.amazonaws.com/testing/messages
#api_gateway_key=
UL0k6X19LmaWR18O0mkCD2CMH6KuBwCO5I7Dv
aXh
```

Figure 38: Text file for configuration the VTN (dras_client.ini). Source: own elaboration [90]

3.4.4.1.2 Creating targets

EPRI's VTN expands upon the OpenADR standard by enabling the creation of custom groups of VENs, known as targets. This streamlines the management of events, as a single event can be linked to multiple targets. It can be associated to all VENs events belonging to those targets. gives the location where you can associate targets for an event. [91]

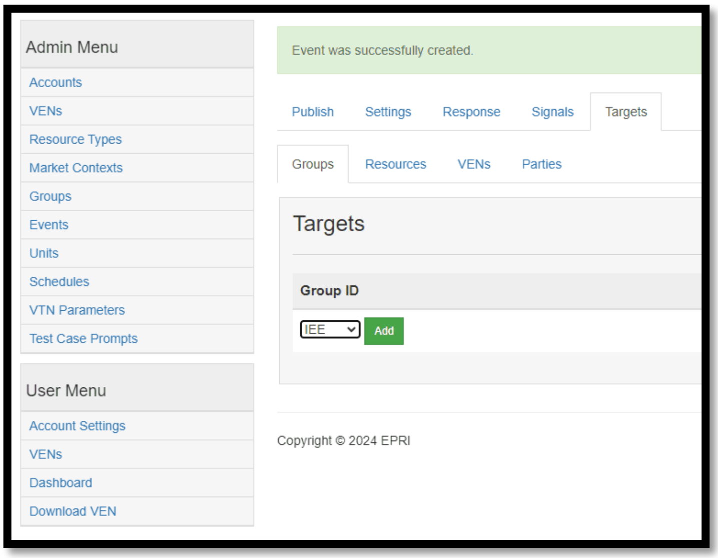


Figure 39: Location for assigning a target. Source: own elaboration

Table 12 and Figure 40 gives a summary of the TargetID's. EPRI's VTN automatically generates a unique target for each VEN upon its creation. This "venID" target enables precise control over individual VENs, as it remains associated with a single VEN throughout its lifecycle. Once targets and events are established within the VTN, linking them allows for the application to target specific VENs. [92]

Table 12: TargetID's summarised. Source: EPRI [92]

targetID	Description
resourceID	This specifies individual devices.
groupID	This refers to a group of devices.
partyID	Not often used, but assigns a location
venID	This describes the VEN with a unique identifier. If none are, every VEN should respond.

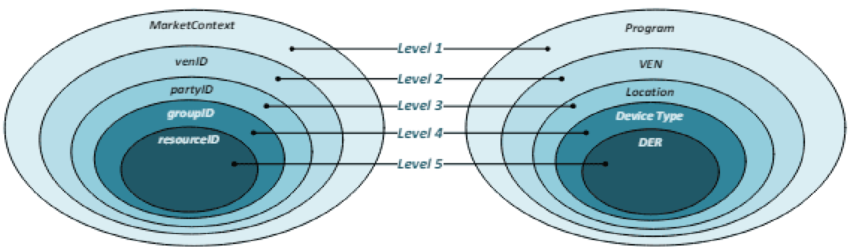


Figure 40: TargetID's and their assigned level of filtering. Source: OpenADR Alliance [93]

3.4.4.1.3 Create a simple event or special event

During a DR event, the utility communicates details about changes to the DER, such as timing of an event. The utility may instruct the DER to make adjustments such as modifying its energy consumption, production, or storage levels. Some typical signals transmitted would specify one or more of the following:

- SIMPLE — Simple levels (OpenADR 2.0a compliant)
- LOAD_CONYROL — Set load output to relative values
- CHARGE_STATE — State of energy storage resource
- ELECTRICITY_PRICE — This is the cost of electricity
- ENERGY_PRICE — This is the cost of energy

A complete list of defined values can be found in Appendix 4. Upon receiving an event signal, a pre-defined action is usually triggered. This includes scheduling load, along with providing relevant details such as pricing, load targets, and specific resources affected. The most important difference between a simple and special event is that a simple event is compatible with OpenADR 2.0a and a special event not. A special event can carry larger payload and transfer more details than a simple event. The following paragraphs outline the steps for generating both simple and special event types. [33], [94]

<u>SIMPLE EVENT</u>

Note that only users with admin privileges can create events. Admin privileges are most of the time managers, engineers who implements the OpenADR protocol, etc.

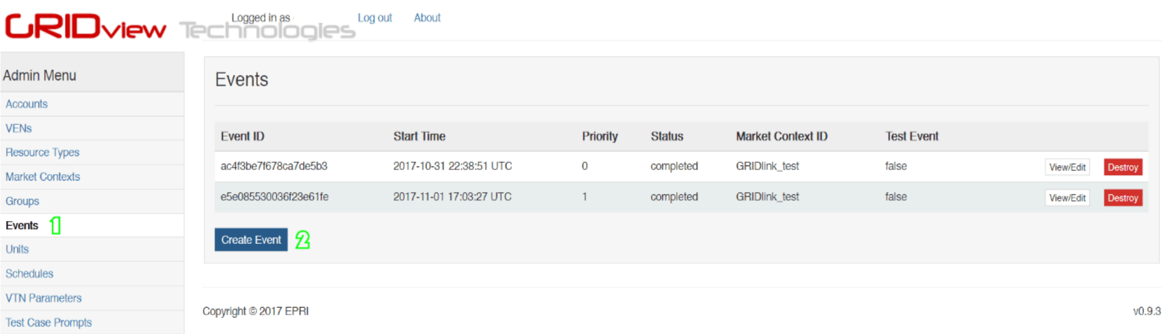
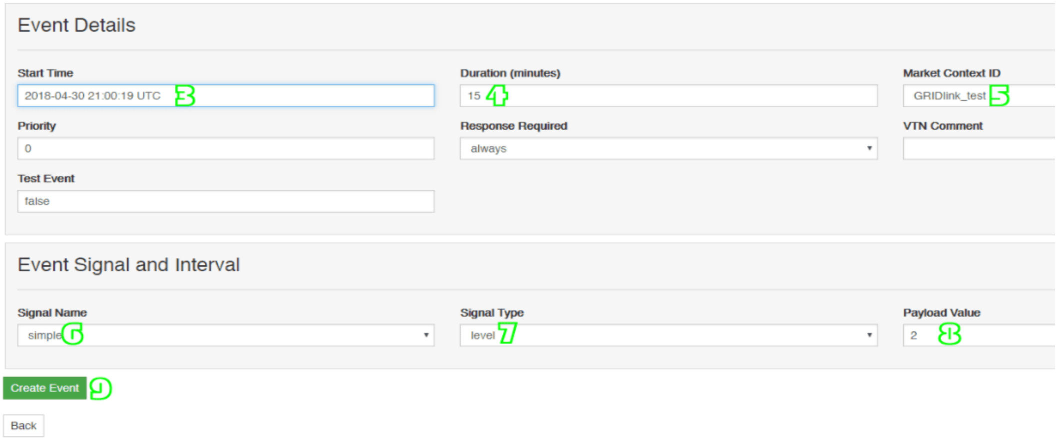


Figure 41: Simple event ; Source: GRIDlink Technologies

From the Dashboard

1. Select Events
2. Create Event

Event Details



In Event Details

3. Modify the Start Time for the Event to begin (Make sure to make this ±2 minutes later then original time so it can be detected!)

4. Enter the Duration in minutes.

5. Select the appropriate Market Context ID. "GRIDlink_test" is generally used for demonstrations but check the "dras_client.ini" file (Figure 38 and Figure 42) in GRIDview to make sure the settings are as follows:

> market_context1=GRIDlink_test
> market_context2=
>
> A blank Market Context ID will result in the GRIDlink participating in all Events regardless of the Market Context.

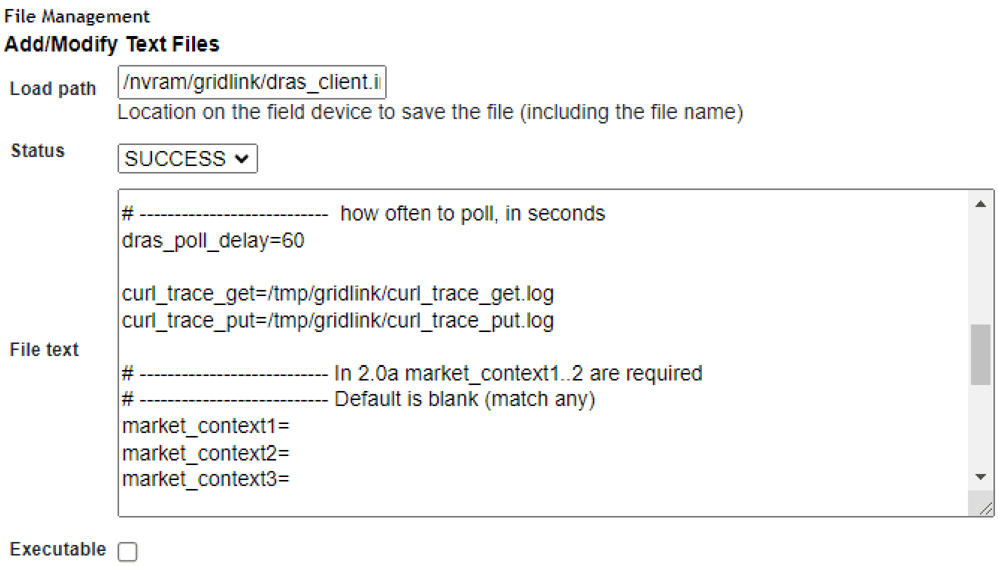


Figure 42: Appropriate Market Context ID. Source: Own elaboration

6. Signal Name: **Simple**

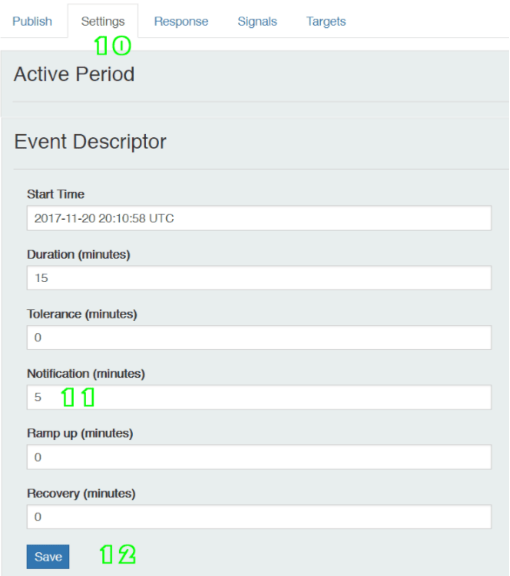
7. Signal Type: **Level**

8. Payload or Signal Value, enter one of the following signal values:

Normal	**0.0**
Moderate	**1.0**
High	**2.0**
Special	**3.0**

9. Create Event

Settings (optional part)



Before Publishing:

10. Select Settings

11. Add any additional variances such as Ramp up or Notification

12. Save

Figure 43: Settings; Source: GRIDlink Technologies

For a better understanding for the different meanings of the technical terms above, refer to Figure 44 and the following descriptions: [95]

- **Duration**: The length of time the actual event lasts.
- **Randomization/Tolerance**: A period before the notification time during which the exact start time of the event is randomized. This helps to avoid simultaneous responses from many devices and prevent grid overload. For example, with a 5-minute randomization window, the VEN can randomly delay its response between 1 to 5 minutes from both the start of the event and the end of the event. So, the total event duration keeps unchanged. It is typically used for thermostat events.
- **Notification**: The period when a notification is sent out, informing relevant parties of an upcoming event.
- **Ramp Up**: The time interval between the end of the notification time and the start of the event. This allows for preparation and gradual transition to the event state.
- **Recovery**: The period after the event ends, during which the system returns to its normal state. [95]

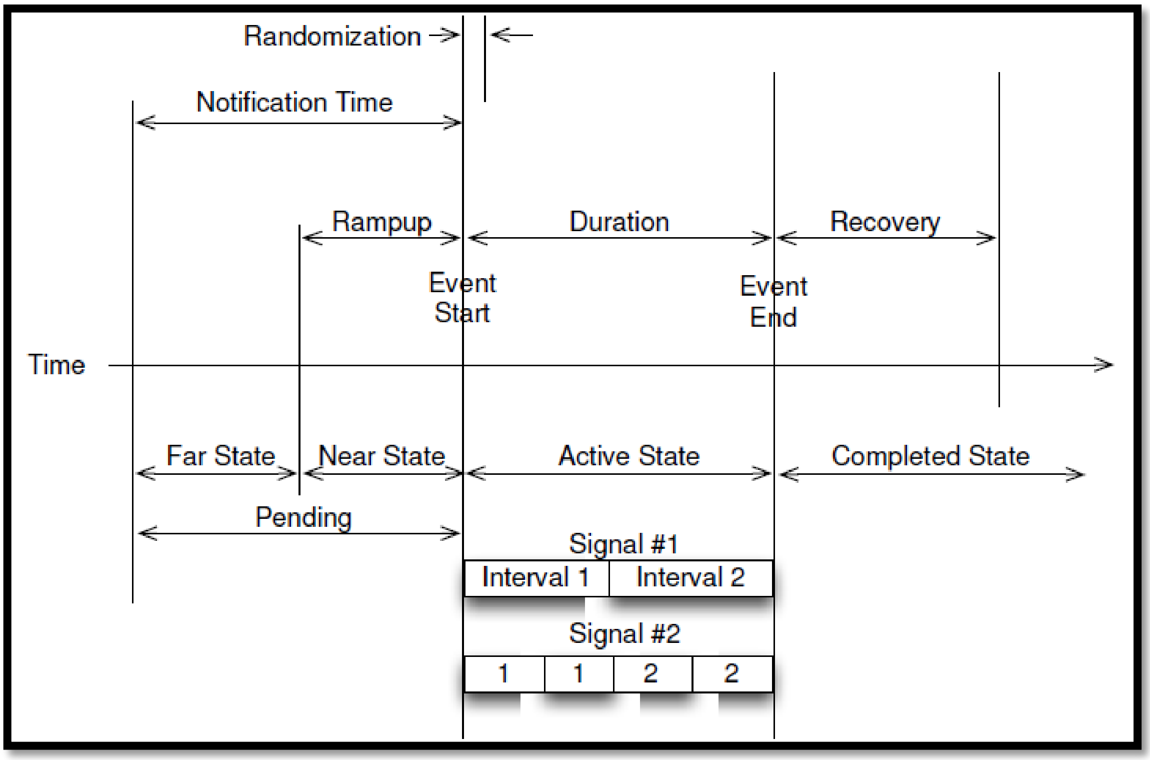
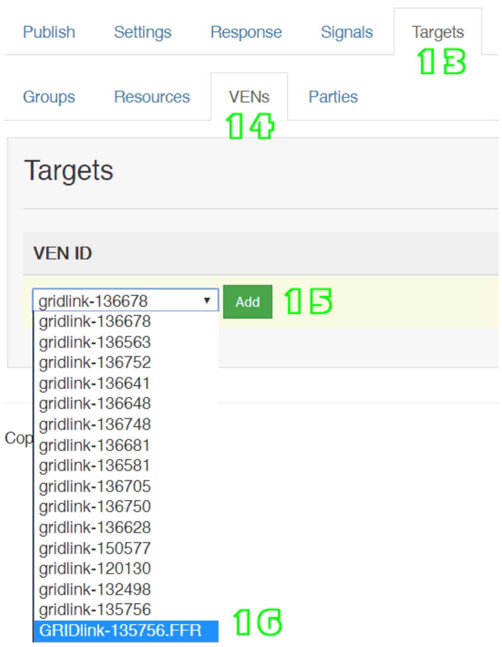


Figure 44: Different time intervals for an event. Source: GridFabric [68]

Targets



Assign which GRIDlinks will participate:

13. Select Targets in main tabs

14. Select VENs in sub tab

15. from the dropdown

16. Select 1 or more VENs from the VEN ID dropdown.

Figure 45: Targets; Source: GRIDlink Technologies

It is important to not include other GRIDlinks in your event.

Publish

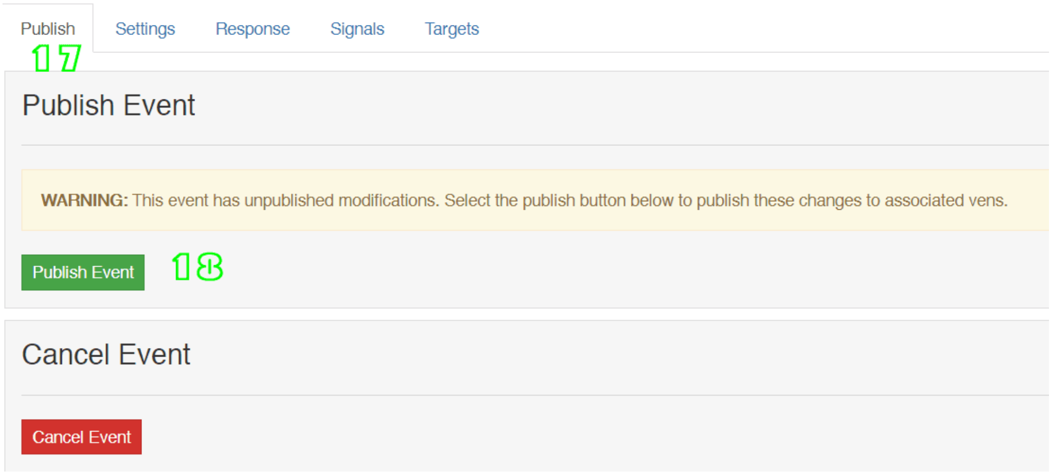


Figure 46: Publish an event. Source: GRIDlink Technologies

17. Select Publish tab

18. Publish Event

Before a new event is scheduled, please **[Destroy]** any finished events.

[94]

<u>SPECIAL EVENT</u>

This is the same procedure as “Create a simple Event” but next steps are different:

6. Signal Name: for a Special Event (not Simple / Level) select LOAD_CONTROL.

7. Signal Type: Select setpoint

8. Payload or Signal Value: enter a 5 digit number in accordance with the program/contract naming convention.

[96]

3.4.4.2 GRIDview NA: user interface for control GRIDlink hardware

GRIDview NA[4] is an interface that can be used for creating events, test a signal, relay configuration and meter data configuration. It is a universal user interface that streamlines the remote operation, data collection and control of commercial and industrial processes.

There are 4 pieces of software running independently of each other in every GRIDlink. Each handles a different function and some monitors others for self-diagnostics. The software architecture can be found in Table 13. [97]

Table 13: Software architecture of GRIDview NA. Source: Own elaboration based on GRIDlink Technologies [97]

Layer	Name of the layer	Discription of the layer
4	sxClient	Secure communications with GRIDview Cloud, data logging, remote command & control.
3	Open ADR Program Stack	Certified software communicating to the VTN to obtain Event info, report meter data and feedback status V 2.0a/b
2	Control Program	ISaGRAF for control logic to outputs, manages how DR events are executed, meter data, instant kW calculation, etc. ISaGRAF is a PLC-like software running on a server.
1	(Hardware level) Firmware	Controls I/O, communication ports (Modbus), register tags.

As earlier mentioned, this thesis is not a manual for the OpenADR platforms. Refer to the official website for full guidelines and the possibilities. For a better understanding for the possibilities, some screenshots are added in Appendix 5.

3.4.4.2.1 Activate a relay from GRIDlink through GRIDview

Testing a signal confirms a successful connection. To send a test signal to the GRIDlink, ensure "Transfer All" is deactivated. If the page displays a green button beside "Transfer All," it is active. In this state, the GRIDlink joins automated DR events. Click the green button and confirm to disable it. (Figure 47) After deactivation, select the relay (1, 2, or 3) that needs to be tested. For 113/213 GRIDlinks hardware, all are accessible. Note that this action activates the attached relay. Shortly, the matching digital output on the unit will turn on (Figure 48), and the corresponding box in GRIDview will become green. [98]

[4] go to https://na.gridview.technology/. More information about GRIDview NA can be found on https://gridviewadr.info/gridview-user-interface/.

Figure 47: Overview of user interface GRIDview NA. Source: Own elaboration

Figure 48: Hardware GRIDlink 113, digital output 1 is activated. Digital output 4 on means VTN connection is established. Source: Own elaboration

3.4.4.2.2 Create an event

As earlier described in section 3.4.4.1.3 for how to create an event, it also possible to create an event in GRIDview NA. The description of the signal names and signal in Figure 49 types can be found in Appendix 1. In section 4.3.3, there is a specific situation described.

Figure 49: Create an event in GRIDview NA. Source: owe elaboration

3.4.4.2.3 Create an event scheduler

This section describes the procedure for creating an event scheduler. (Figure 50)

Figure 50: GRIDview overview for event scheduler. Source: GRIDlink Technologies [99]

<u>1. Enter Event Parameters</u>

Start Day

Valid entry 1-31. If the day is greater or equal to today's date then DRES will assume the Event is scheduled for today or later this month. If the day is less than today's date then DRES will increment to the following month or year if the current month = 12.

Hour

Valid entry 0-23. Local time. A time cannot be entered earlier than the current Hour for an Event scheduled today.

Minute

Valid entry 0-59. A time cannot be entered earlier than the current Minute if the Event is scheduled for the current Hour today.

Pending Notice Minutes

Valid entry 0-1440 (0-24 hours). This determines how many minutes before the Event start time Relay 1 changes state.

Event Duration Minutes

Valid entry 0-1440 (0-24 hours). This determines how many minutes Event Relays are energized.

Signal Value

Valid entry 1-2.
1 = Moderate which changes Relay 2 state.
2 = High which changes Relay 3 state.

2. Number of Events
Valid entry 1-120. A value greater than 1 repeats the Event in sequential days.
Example: if a user wants the same Event repeated Monday through Friday, simply schedule an Event on Monday and enter 5 for the number of Events.

An entry of 30 would repeat the Event every day for 30 days.

If the user does not want to have Events on weekends then the option would be to schedule 4 Events each starting on the target Monday with 5 for the number of Events. Once a value greater than 0 is sent for the Number of Events, it will be scheduled.

3. Events queue
The scheduled Events are listed with parameter details.

4. Delete Event
The user may delete any Event here. It is recommended to schedule Events with enough advance time to review and delete if an input error is found.

5. Opt Out
The user may choose not to participate or Opt Out after the Event has started. This will release all relays and end the Event. Opt Out is also tied to a digital input on the GRIDlink so a physical Opt Out button can be used locally.

6. Relay State
Relay state can be viewed in real time.

7. Event History
Relay state is datalogged and can be reviewed in a Trend screen during and after the Event. shows a trend chart of the event history. Green indicates a pending event, light blue indicates a special event, dark blue indicates a moderate event, and red indicates a high-priority event.

[99]

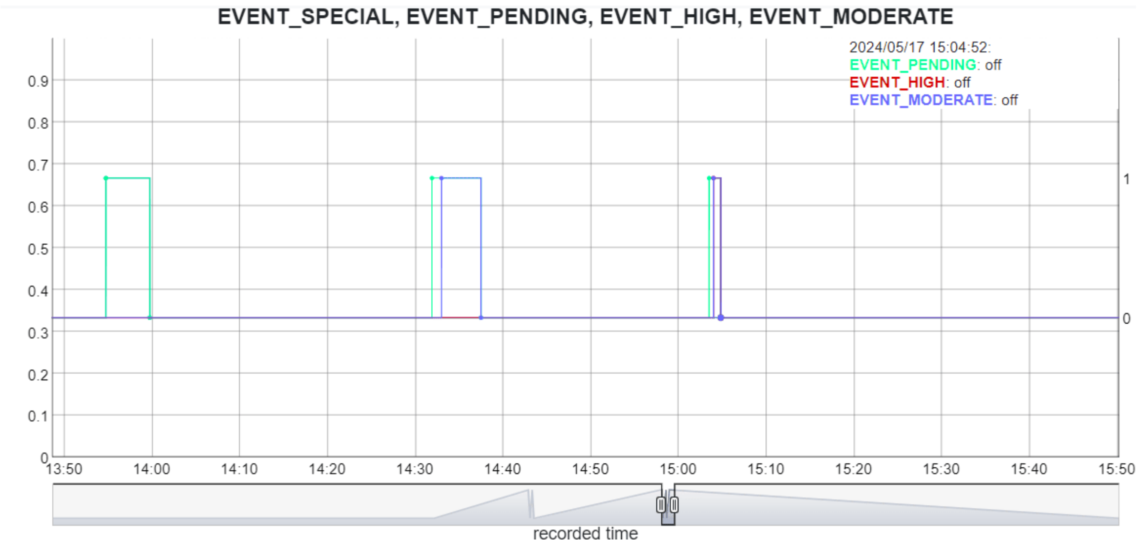


Figure 51: Trend screen of an event history. Source: Own elaboration.

3.4.5 Virtual End Node (VEN)

For the VEN you can install software on a server or a computer for running. Another option is to install hardware local where the DER controller will be activated like in a factory. Each option has his advantages. For example, a software-based VEN is more cost-effective to scale up and log information is easier to analyse. A hardware-based VEN can offer extra physical security for sensitive DER control and have more possibilities to integrate other hardware.

3.4.5.1 VEN software user interface EPRI OpenADR (Desktop Client)

Figure 52 gives the main user interface options for the VEN software. For in-depth instructions and details, please consult the manual. [100] Some summarised information can be found in Figure 52 and the text below:

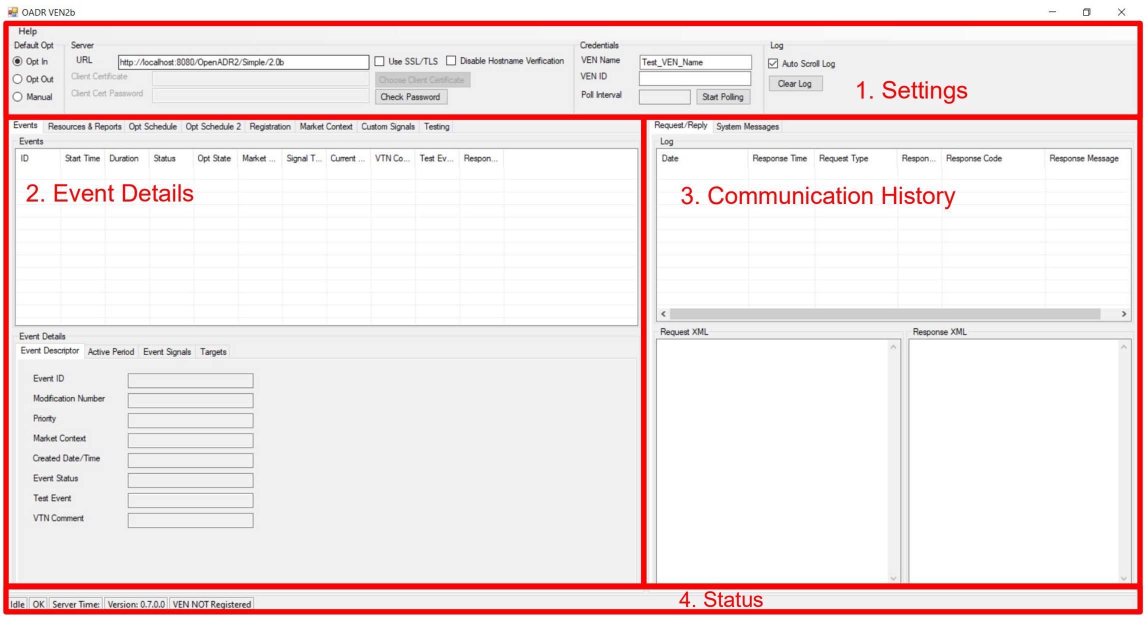


Figure 52: Main possibilities for VEN user interface EPRI OpenADR (Desktop Client) Source: Own elaboration

Section "Settings" allows users to configure various settings for the VEN for establishing a connection with the VTN. This includes: [100]

- **Default Opt** describes the availability and the ability to send, cancel or modify a schedule:
  - **Opt In**
    The VEN will take part in an event. For the EiOpt service, a type of schedule that specifies the availability of the resource.
  - **Opt Out**
    The VEN will not take part in an event. For the EiOpt service, a type of schedule that specifies the unavailability of the resource.
- **URL** specifies of the Virtual Top Node (VTN), the server-side software managing the demand response program.

- **Client Certificate & Password** provides authentication credentials for secure communication with the VTN.
- **SSL/TLS** enables secure communication.
  VEN name, password and preferences like poll interval and auto scroll log.

Section “Event Details” contains tabs that show the status and state of the four core OpenADR services: [100]

- **Events**
  This tab displays information about demand response events received from the VTN, such as event IDs, start and end times, and event status. It also allows users to create and send event responses back to the VTN.
- **Reporting**
  This tab is used for managing reports sent to the VTN, including meter readings and other relevant data.
- **Opt**
  This tab allows users to schedule opt-in or opt-out periods for demand response events.
- **Registration**
  This tab handles the registration process of the VEN with the VTN.

Section “Communication History” displays a log of all OpenADR messages exchanged between the VEN and VTN. Users can select a message to view the associated request and reply messages in XML format. This information is crucial for troubleshooting and analysing communication issues. [100]

Section “Status” displays information about the current state of the VEN, including VEN polling status, last message status, VEN version and OpenADR registration state. [100]

Some advantages of this system are the following:

- ✓ The XML request is clearly to analyse.
- ✓ The log history gives you precisely which message has received or which error has occurred.
- ✓ More cost-effective for scale-up. Only software is cheaper than hardware. But limited control.

3.4.5.2 VEN hardware GRIDlink VT-IPM2M 113 series

This section describes how a typical OpenADR signal works with the hardware. In Appendix 2 you can find the detailed specifications of the used hardware in the lab.

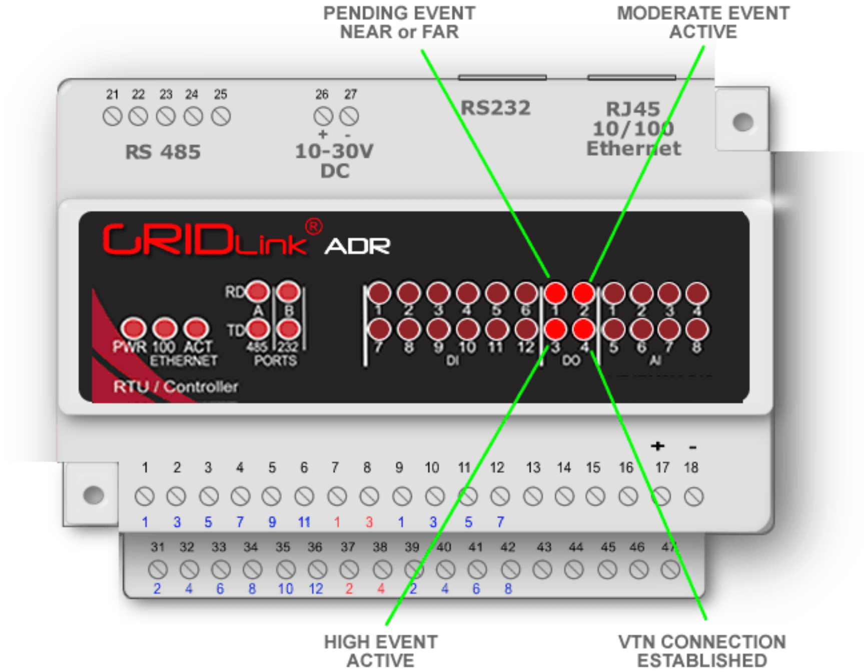


Figure 53: Description of event LEDs: Source: GRIDlink Technologies [101]

A typical OpenADR Signal has 2 parts:

1. Event Notification
2. Active Event

When the Utility decides to schedule a DR Event, it usually scheduled sometime in advance. This could be as long as 24 hours or as short as 10 minutes depending on the contract. As part of that contract, the utility agrees to give **Notice** at a pre-agreed time. That **Notice** period could include an email, telephone call or other form of human-to-human communication. [101]

The signal from the utility server (Virtual Top Node) also sends a **Notice** to the GRIDlink which is a time prior to the **Active Event**. It could be several hours or minutes. This is called a “**Pending Notice**” and is represented by DO1 illuminating. DO1 represents a digital output to terminal 7 which can optionally energize a relay. This relay can be used to rotate a beacon or other alarm device or be used to pre-cool an area or some other strategy. [101]

When the **Event is Active**, it can be a **Moderate** (DO2 – terminal 37) or **High** (DO3 – terminal 8) signal which controls the load to be shed. The **Moderate** signal is not used by all Utilities but allows a lower level of load shed depending on how the relays are wired. It has also been used by some Utilities as a load “**consume**” logic as well. DO4 indicates there is a connection to the Utility VTN. [101]

Some advantages of this system are the following:

- ✓ Clearer visualisation then software based VEN.
- ✓ Wide accessible for activating DER controller. More robust.
- ✓ Extra possibilities for integrating other hardware.

3.5 Evaluation developed during the DRIP

For validating and verifying results, the methodology is based on a simulation tool developed during the Demand Response in Industrial Production (DRIP) project. DRIP was a multi-party cooperation of a research centre, industrial customers, a grid operator retailer and a certifier. Figure 54 gives an overview. DRIP uses a simulation tool for validating the environmental, technical and economic aspects. More information about the simulation tool can be found in this section. [13]

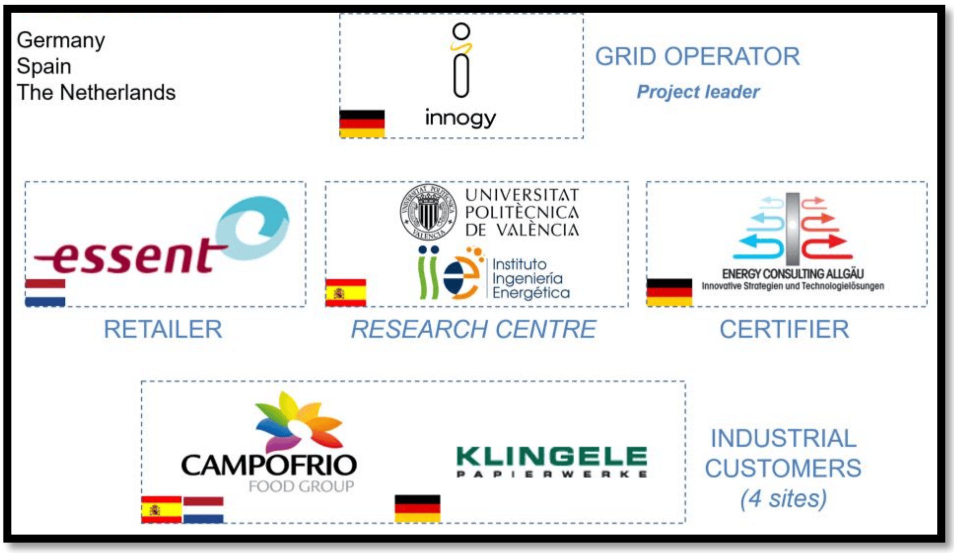


Figure 54: Multi-party cooperation of DRIP. Source: DRIP [13]

The electricity demand is primarily driven by five sectors: agriculture, residential households, services, transportation, and industry. Within the European Union, the industry is by far the largest DR potential. DRIP focuses on this industry sector for optimizing the electrical peak capacity. [13], [74]

The case study was evaluated using the DRIP simulation tool, which is based on Matlab and available in the Laboratory of Energy Systems and Markets (e-SYM) at the Institute for Energy Engineering of the Polytechnic University of Valencia (UPV). The DRIP project sought to create a method for assessing customers' flexible energy demand and to measure the advantages across the electricity supply chain in three key areas: [102]

- Technical: enhanced grid stability and efficiency
- Environmental: reduction in CO_2 emissions
- Economic: optimized integration of energy resources

In chapter 4, section 4.4, will the proposed evaluations will be tested using real data from food factories.

Required information for the simulation tool

The simulation tool is focused on the industrial customer in a particular reserve energy market. Figure 55 shows an overview of the required information (inputs) and the main results of the simulation tool (outputs). It is a set of information related to the customer, the reserve energy market prices and CO_2 emission factors. So, in general for practical implementation of this tool, it is crucial to consider two primary data sources: [73], [102]

- **Industrial customers**
  These provide essential information regarding process load curves, general operations and electricity contract pricing.
- **Websites of TSOs**
  These platforms offer insights into real-time market prices for electricity.

Note that CO_2 emission factors are typically not publicly accessible, and obtaining hourly load curves can be challenging. Additionally, extra actions can be implemented, such as utilizing batteries for energy storage.

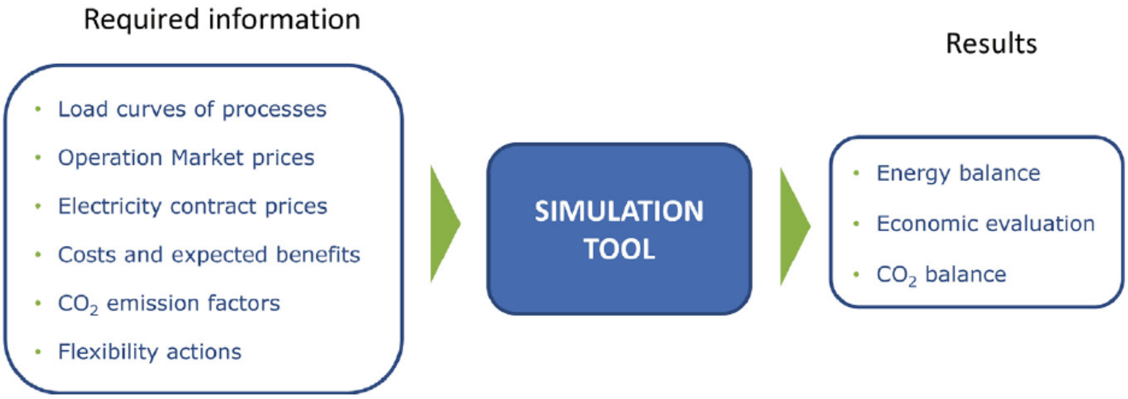


Figure 55: Inputs and outputs of the simulation tool of DRIP: Source: DRIP [73]

A more detailed description of the inputs can be found below:

- Input from **load curves** from industrial processes can be achieved by installing smart telemetry for the most important industrial processes of a factory. The total load curve is also needed for the simulation tool.
- Provide **electricity prices of the selected operation markets**. This is specific for the country where the factory is located. For example, in Spain you find the electricity prices on https://www.esios.ree.es/es/analisis.
- Input the **specific electricity contract prices** that the factory has with its energy supplier. This could include fixed rates, variable rates, or a combination of both.
- Gather data on the **costs** associated with energy consumption and potential **expected benefits** from energy-saving
- **CO_2 emission factors** can be found in reports of environmental organizations.
- **Flexibility actions** refer to the ability to modify the typical energy consumption patterns of an industrial process without affecting the final product's quality or quantity.

A detailed description how the simulation tools works is out of scope of this thesis. Refer to “Simulation Tool Guide of DRRIP” for detailed guideline. [102] Only important working principles are described in the next sections.

3.5.1 Technical

Quantifying the absence of consumption is a central challenge in Demand Response. Since it is impossible to definitively know how much energy would have been used without the intervention, the best approach involves establishing a baseline. The baseline represents the expected consumption under normal circumstances, allowing for comparison with actual consumption during DR events. Defining and calculating this baseline can be challenging. Currently, there is not a standardized approach for the baseline. Many regions opt for simplified methods, such as using the average consumption from the past 10 similar working days.

3.5.1.1 Identifying and utilizing typical daily consumption patterns

The next step involves defining “typical days” which represent recurring daily electricity usage patterns for the consumer. To achieve this:

1. Exclude days with unusual data (e.g., outages, missing data).
2. Group remaining days based on similar consumption patterns.
3. Calculate the average consumption for each group. When the standard deviation value of all the groups becomes acceptable = “typical day” profile.

The simulation tool of DRIP can assist in this process. [102]

3.5.1.2 Defining DR actions

Once typical days are established, specific DR actions are defined for each process within the consumer's operations. These actions are characterized by technical parameters that vary based on day type and month, considering factors like external temperature and production schedules. Figure 56 illustrates a theoretical load curve where energy consumption is intentionally reduced (E_1) for a specific duration (T_D). Additional energy is used before (E_2) and after (E_3) this reduction for making adjustments and re-establishment. The load curve eventually returns to normal. The consumers receive advance notice before implementing the action. This is characterised by T_{IA}. All technical parameters can be found below:

- **Δ_{PR1}** Maximum Reduced Power in kW
  The assured maximum power reduction below the expected value that a flexible process can achieve during a DR event. Determined from the lowest power reduction observed during practical tests.
- **Δ_{PR2}** Increased Power for Preparation in kW
  Additional power needed to store energy before load shedding to ensure smooth implementation without disrupting production.

- **Δ_{PR3}** Increased Power for Recovery in kW
  Additional power required after load shedding to restore normal operating conditions and prevent product quality issues.
- **T_D** Duration of Action in hours
  Maximum duration of a load reduction to maintain product quality.
- **T_{PR}** Preparation Period in hours
  Time needed before load shedding to adjust the flexible process for reduction or interruption.
- **T_{RC}** Recovery Period in hours
  Time after load shedding for the process to return to normal operation.

[73] [103]

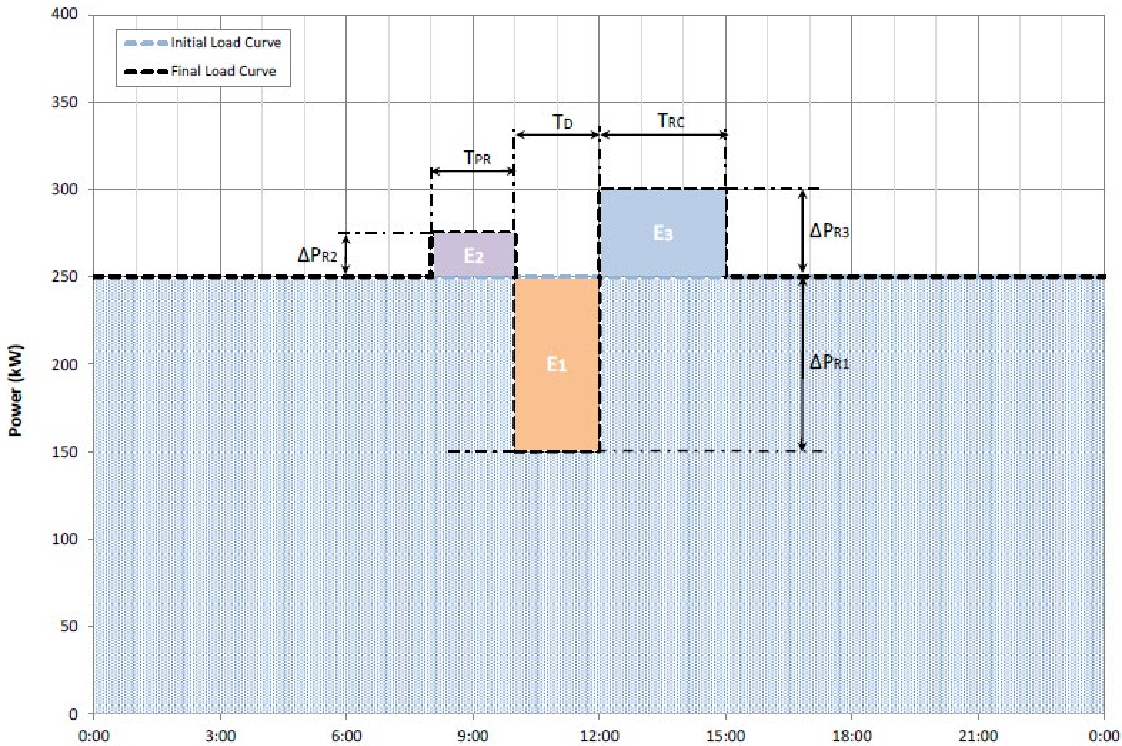


Figure 56: Technical parameters. Source: DRIP [103]

The energy balance (EB_{Total}) involved in the DR process i in the month I is calculated as the difference between the energy reduces during the DR events (E1) and the additional energy consumed before and after these DR events (E2 and E3 respectively): [73]

$$EB_{TOTAL} = E_1 - (E_2 + E_3) = \sum_{h=1}^{p} E_1^h - \left[\sum_{h=1}^{p} E_2^h + \sum_{h=1}^{p} E_3^h \right] \quad (2.1)$$

where h is the number of the DR event and p is the total number of DR events in the month i.

3.5.1.3 Defining flexibility action

After defining specific DR actions, the simulation tool utilizes "flexibility actions." These allow adjusting energy use without impacting product quality, as in section 3.5 is described. Many mid-sized industrial consumers lack awareness of their energy consumption patterns and potential flexibility in production, often due unavailability of energy experts in the factory. To remedy this, a flexibility audit is necessary to analyse electrical consumption and identify potential DR actions. Each flexibility action is characterized by a process and a type of day. For each flexibility action can parameters be specified like “Interruptible power in kW”, “Starting time of interruption” or an action cost. To fill this part correctly, the flexibility audit for the factory should be reviewed first. For a full overview for technical and economical specifications, refer to the guideline of DRIP. [102]

3.5.2 Economic

3.5.2.1 Identification of the availability: assessing flexibility activation

Flexibility is evaluated to determine if a DR process i can be interrupted at a specific time j. When a DR process is available for interruption (Sij = 0), an economic assessment is conducted to calculate the decision margin (M_D), which is the difference between the real benefit (B_R) earned by the industrial customer in the reserve energy market and the expected benefit for the customer (B_{NE}): [73]

$$M_D = B_R - B_{NE} \tag{2.2}$$

This parameter M_D verifies the potential participation of a customer in a DR program at a specific time:

- If MD ≤ 0, the customer will not participate due to lack of economic gain.
- If MD > 0, the customer will provide DR services, adjusting power load to meet DR event requirements and reap financial benefits. [73]

3.5.2.2 Customer profitability calculation

In order to calculate the real benefit (B_R) at the quarter-hour, several factors are considered such as the economic balance (S_S), the benefit of the extension of machinery useful life (S_{MA}), the variable costs (C_{VAR}) and the payment offered by the TSO in the reserve energy market (P_M):

$$B_R = S_S + S_{MA} + P_M - C_{VAR} \tag{2.3}$$

A/ S_S The economic balance [73]

The economic balance (S_S) during a DR event is the difference between the economic savings due to the energy not consumed S_1 and the extra costs generated by the additional energy consumed before and after the interruption (preparation S_2 and recovery periods S_3):

$$S_S = S_1 - (S_2 + S_3) = \sum_{k=1}^{3} E_1^k \cdot p_k - \left[\sum_{k=1}^{3} E_2^k \cdot p_k + \sum_{k=1}^{3} E_3^k \cdot p_k\right] \tag{2.4}$$

where p_k is the electricity price in the time period k (i.e. prices of electricity for on-peak, shoulder and valley periods.)

B/ S_{MA} The benefit of the extension of machinery useful life [73]

Stopping production during a DR event can extend machinery life, creating economic savings. However, frequent start/stop cycles may shorten lifespan, resulting in no S_{MA} and potential extra costs counted as variable costs.

C/ P_M The payments from the system [104]

The payment offered by the TSO in the reserve energy market.

D/ C_{VAR} The variable costs [73]

These costs are linked to the DR implementation, such as labour costs for overtime work and if exists cost due productivity loss.

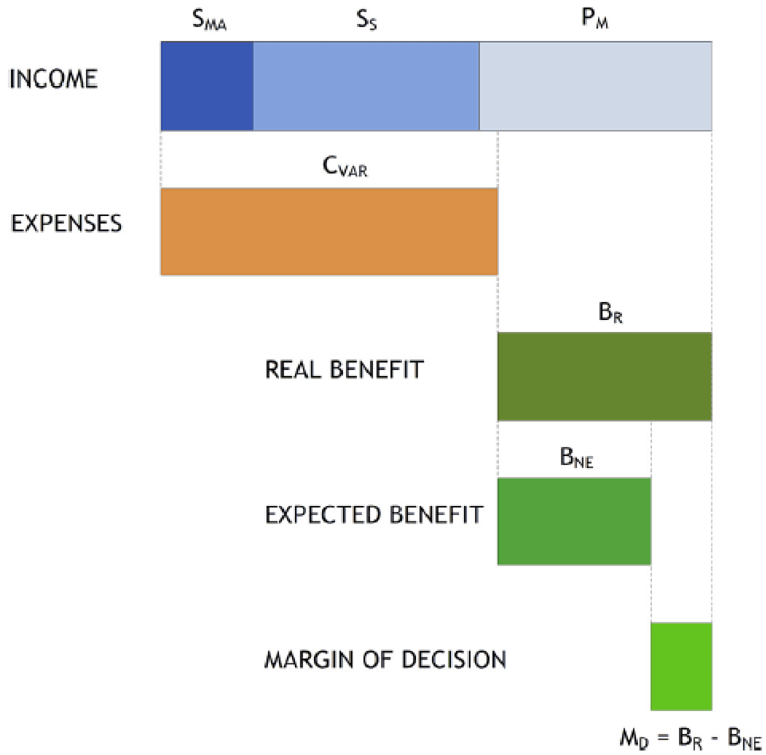


Figure 57: Evaluating the economic impact for customers. Source: DRIP & paper Energy [73]

Taking into account the previous considerations, it can be concluded that the revenue offered by the TSO (marginal price) has to be higher than the minimum price required by the customer. In this case, the matching will be achieved and the DR process i will be interrupted during the quarter-hour j (Sij = 2), reducing the available interruptible power (Pij). Otherwise, the customer will not tender the flexible power. The following equation summarizes the above statements:

$$P_M \geq C_{VAR} + B_{NE} - S_S - S_{MA} \quad (2.5)$$

In conclusion profitable if:

$$P_M > C_{VAR} + B_{NE} - S_S - S_{MA} \quad (2.6)$$

[73]

3.5.2.3 Unitary action cost

In the simulation tool there is also an input for “unitary action cost". Flexibility actions in DR involve both direct and indirect costs for customers, which are quantified as the "unitary action cost" in the simulation tool. The formula for this cost encompasses:

$$C_F = C_{DIRECT} + C_{INDIRECT} = (C_C + C_{MM} + C_{AM} + C_{AS}) + (C_{LB} + C_{PR} + C_{OTH}) \quad (2.7)$$

Direct costs relate to the technical capacity for carrying out a flexibility action. These include:

- C_C: Cost of control
  Expenses for purchasing and installing the control system.
- C_{MM}: Cost of monitoring and metering
  Expenses for purchasing and installing the monitoring and metering system.
- C_{AM}: Amortizations
  Annual amortization of investments in equipment and facility adaptations for DR, including initial expenditures like engineering efforts and prequalification of technical units.
- C_{AS}: Cost of alternative dual supply
  Costs for alternative energy sources (e.g., fuel, gas) and their maintenance during electricity reduction.

  Note that C_C, C_{MM} and C_{AM} are evaluated with the purchasing budget or past experiences in similar facilities.

The **indirect** costs refer to those incurred as a consequence of the implementation of flexibility action. These include:

- C_{LB}: Labour cost
  Additional payments for overtime, work during expensive hours, unemployment during interruptions, and coordination of DR actions. It is Determined by the customer based on staffing and time requirements.
- C_{PR}: Impact in the production cost
  Indicates loss of product quality or productivity. Difficult to evaluate, but crucial for customers to assess potential impacts. It can only be evaluated by the customer.
- C_{OTH}: Other cost
  Any additional costs not covered by the specific categories above.

[102], [104]

3.5.3 Environmental

The overall environmental effect of all DR events within a month is determined by calculating the net CO_2 emissions (CE_{TOTAL}). CE_{TOTAL} is calculated as the difference between avoided CO_2 emissions (CE_1) and additional emissions from increased electricity use before and after the events (CE_2 and CE_3):

$$CE_{TOTAL} = CE_1 - (CE_2 + CE_3) = \sum_{k=1}^{n} E_1^k \cdot f_k - \left[\sum_{k=1}^{n} E_2^k \cdot f_k + \sum_{k=1}^{n} E_3^k \cdot f_k\right] \qquad (2.8)$$

Here, “k” represents different time periods, each with its own CO_2 emission factor (for example peak, shoulder, and off-peak). It is crucial to note that this calculation only focuses on the CO_2 impact of electricity usage. Emissions from other fuel uses (heating, transport, etc.) are not included in this analysis, as they fall outside the scope of this study. Note that CO_2 emission factors are typically not publicly accessible. But they can be found in reports from electricity systems of the country or in reports in local institutes for energy diversification and saving. [73]

The environmental impact of DR strategies is dependent on the specific country. Some examples of the DRIP project explained this. In southern countries such as Spain, the current implementation of DR can lead to a reduction in carbon emissions. In contrast, in Central Europe like Germany and the Netherlands, DR strategies might result in an increase in CO_2 emissions due to the composition of their generation mix and the technologies employed for balancing purposes. DRIP indicates that by 2030, with a substantial penetration of renewable energy sources based, nearly all energy during low-demand periods could be generated from renewables. In such a future scenario, the DR would likely result in a reduction in CO_2 emissions. [105]

4 Application - case study

In this case study the focus will be activating a DR program in the industrial sector, esp. the food industry. It is an application to a group of medium-sized industries located in Spain with an aggregated consumption of 120 GWh/year. As exchange protocol OpenADR is used. The assessment of flexibility is conducted using the procedure developed during the Demand Response in Industrial Production (DRIP) project, what was described in section 3.5. It will be limited to a specific set of food factories.

Food production consumes a substantial amount of energy, making it a prime candidate for DR programs. However, companies have been reluctant to participate due to concerns about potential impacts on product quality. The DRIP project has successfully shown that DR actions can be implemented without affecting product quality, paving the way for greater industry participation in energy-saving initiatives. Some results can be found in section 4.4. [74]

4.1 Identification

For a better understanding, the demand response program that we are using in the case study is going to be more defined by a classification as shown in Figure 31 from section 3.3. This case study works in DR based on offered motivations, more specific incentive-based DR. This type of program offers users direct financial incentives, such as discounts or rebates, for reducing their energy usage during peak times. Examples can be found in section 2.5.5.

These incentive-based DR program can be more defined in direct and indirect control. In this case study it is the indirect control for ancillary services market program. In an ancillary services market program customers are paid to provide services to the grid, such as frequency regulation or voltage support. Such program is primarily aimed at large industrial users. The typical notification time for an ancillary services market program is 1 to 2 hours. (Table 10) Note that notification time is the amount of advance notice given to participants in a DR program to adjust their electricity use. It is different from the rampup time described in section 3.4.4.1.3. [72], [78]

For a DR program, it's important to understand the specific regulations governing your participation. As mentioned in section 3.3 above Figure 31, there are different regulations. DR can be used as an ancillary service for in secondary reserve, tertiary reserve or replacement reserve. Here is a summary what these balancing services means in Spain:

- **Secondary regulation**
  Secondary regulation is a service that maintains the electricity grid's balance between power generation and demand. It works within a timeframe of 20 seconds to 15 minutes. This service is comparable to the European standard product termed automatic Frequency Restoration Reserves (aFRR). [106]

  Each day, the master regulator publishes the secondary regulation reserve requirements, both upward and downward. Upward regulation means producing more power or using less while downward regulation means producing less power or using more. Negative prices for upward regulation mean power producers are paid to make more or use less. Negative prices for downward regulation mean power producers are paid to make less or use more. [107], [108]

  This service is regulated through market mechanisms for two concepts: availability (regulation band) and net use (energy). The regulation band is remunerated at the marginal price resulting from the allocation. It is planned to evolve in Q2 2024 to two separate reserve markets (up and downward). The secondary regulation energy used for real-time regulation is valued at the marginal price of tertiary regulation energy required to replace this net use of secondary regulation energy. [107]

- **Tertiary regulation**
  Tertiary regulation is an active power reserve activation balancing service that aims to maintain the frequency and generation-demand balance of the system. This service, which is manually activated in a time equal to or less than 15 minutes, is managed by the master regulator through market mechanisms and allows the restitution of the use of automatic secondary regulation reserve. Also, the active power can be offered by a scheduling unit in a maximum time of 15 minutes, and which can be maintained for at least 30 minutes. [107]

  Tertiary regulation energy is paid at marginal price, through a scheduled allocation process (15 minutes before the scheduling period) and, where appropriate, direct activations, within the quarter hour. This service corresponds to the European standard product called manual Frequency Restoration Reserves (mFRR). [106], [107]

- **Activation of balancing energy from replacement stocks (RR)**
  This is a balancing service for the activation of active power reserves that aims to resolve deviations between generation and consumption that may be identified after the closing of the intraday market and to restore or maintain the level of manually and automatically activated frequency recovery energies (secondary and tertiary regulation energies) required in order to prepare for additional system imbalances. This service, which is manually activated in a time equal to or less than 30 minutes, is managed by the European platform, thus complying with the requirements of article 19 of the Electricity Balancing Regulation. [107]

4.2 Practical design architecture for the aggregation with OpenADR

Figure 58 shows a practical application in lab conditions of the methodology from section 2.5. In this application the VTN uses a server from GRIDlink Technologies where execute all the events. The VEN is locally installed in the lab and is hardware from GRIDlink Technologies, GRIDlink VT-IPM2M 113 series. (Figure 59) Figure 60 shows that led DO4 is on. It indicates that the VEN has an establishment with the VTN, as explained in section 3.4.5.2. Cloud-based VENs are predominantly utilized in residential and commercial settings due to the prevalence of numerous small-scale loads managed by smart technology. In a real-world scenario, the VEN is typically hosted on the infrastructure of the company. The already existing control systems of the company (for example a PLC) can handle the logic required to respond to OpenADR signals. It is the most feasible for large-scale implementations because it spares utilities from the intricate task of managing each individual device. [51]

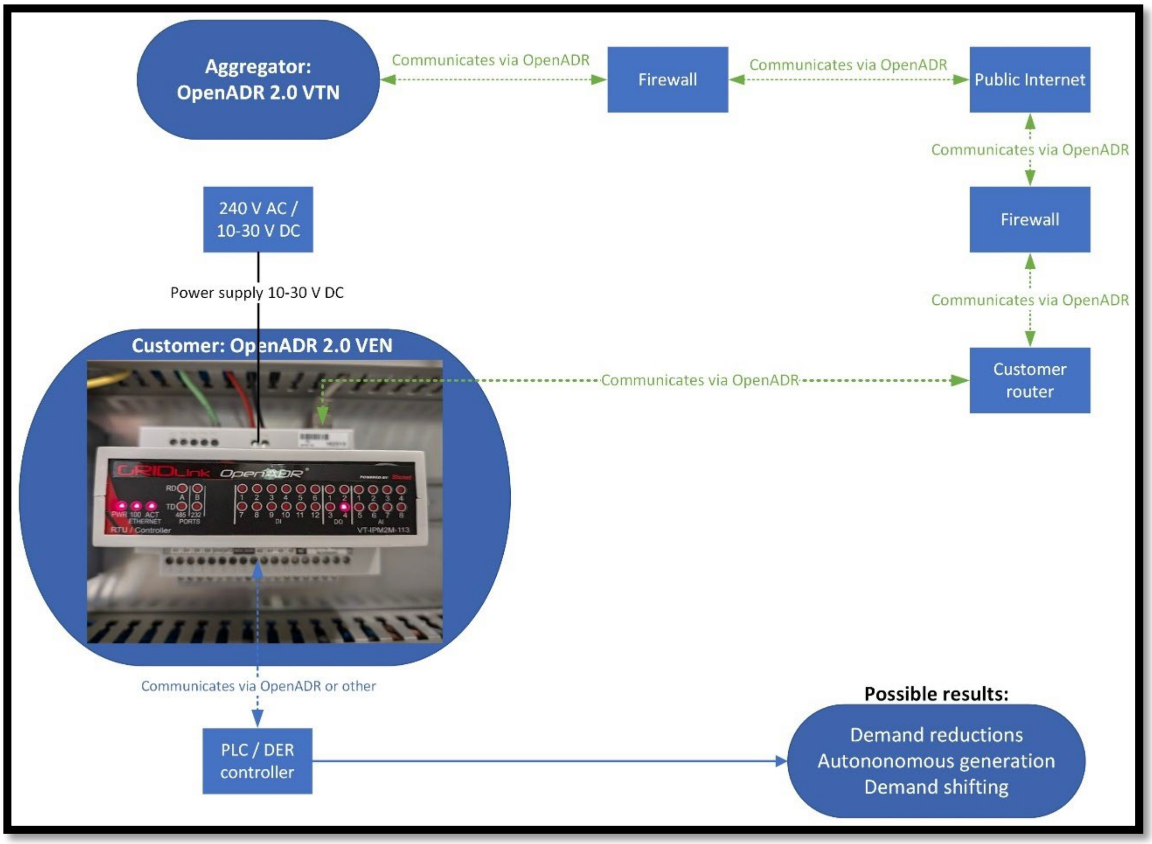


Figure 58: Practical application for the aggregation with OpenADR. Source: Own elaboration

As communication between the VEN and the VTN OpenADR is used. As earlier mentioned, OpenADR is primarily a messaging framework that facilitates information exchange rather than directly controlling devices. Product manufacturers prefer to manage user experiences and responses to grid demands independently. Utilities possess expertise in grid operation but not necessarily in load control. OpenADR's role is confined to providing information about load shifting needs. The device owners determine the most appropriate response and participate based on their own logic on their DER controller. [49], [56]

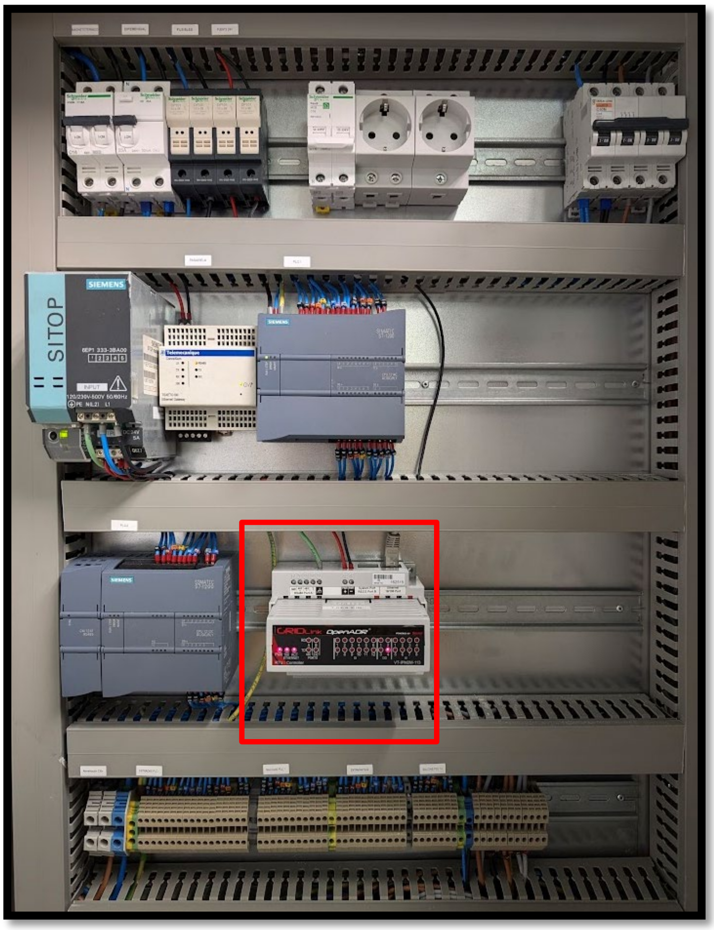


Figure 59: Installed hardware GRIDlink VT-IPM2M 113 series in the lab environment. Available at the e-SYM lab. Source: Own elaboration

Figure 60: Close-up for the installed hardware. Available at the e-SYM lab. Source: Own elaboration

4.3 Applications of the used platforms for OpenADR by GRIDlink Technologies

In this section some instructions will be provided what was executed on the OpenADR platforms and how the results are. There are a lot of possibilities on these platforms, but this document will focus on the key aspects related to the methodology.

4.3.1 Check if the VEN is online

Before you can activate correctly an event, it's important to verify if the VEN has established a connection with the VTN. One method is to check if the LED DO4 is on on the GRIDlink hardware, as described in section 3.4.5.2. Another possibility is to use the VEN software (OADR VEN2b) that can be installed on a server, laptop or desktop. For detailed instructions on the software, refer to section 3.4.5.1. The following settings are used to connect with the VTN. These are obtained from the GRIDview2b website[5] (Figure 61) and GRIDview NA website[6] (Figure 62). The result can be found on figure Figure 63.

URL server

http://vtn.gridview2b.com/OpenADR2/Simple/2.0b

Note that a client certificate is not necessary for simulation environment but for obtaining a certificate for OpenADR see section 2.5.4.6.

VEN Name

162515 - IEE Simulation Lab

VEN ID

13b915c0b83460626f3c

[5] https://vtn.gridview2b.com/vens/all

[6] https://na.gridview.technology/hmi/dev/379/files/

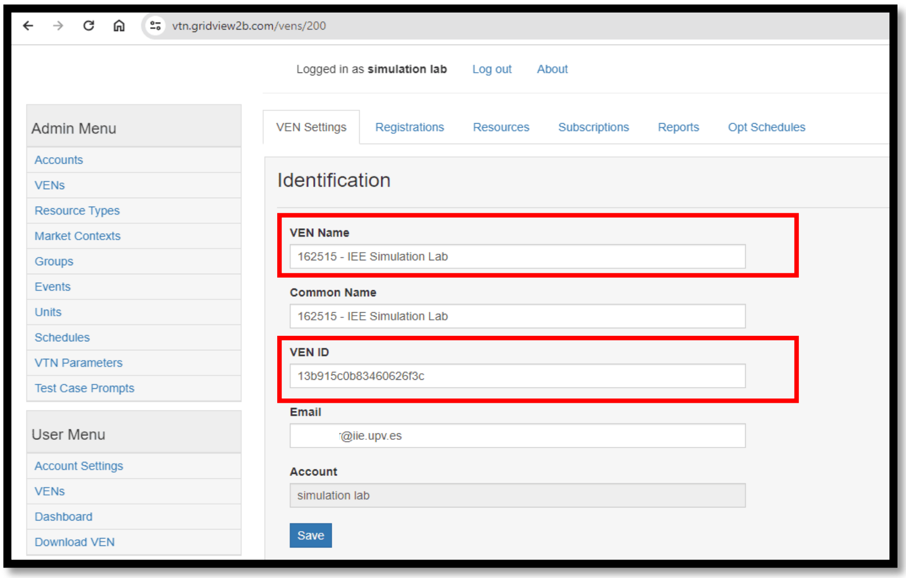


Figure 61: Gathering information for the VEN software from GRIDview2b. Source: Own elaboration

Figure 62: Gathering information for the VEN software on GRIDview NA. Source: Own elaboration

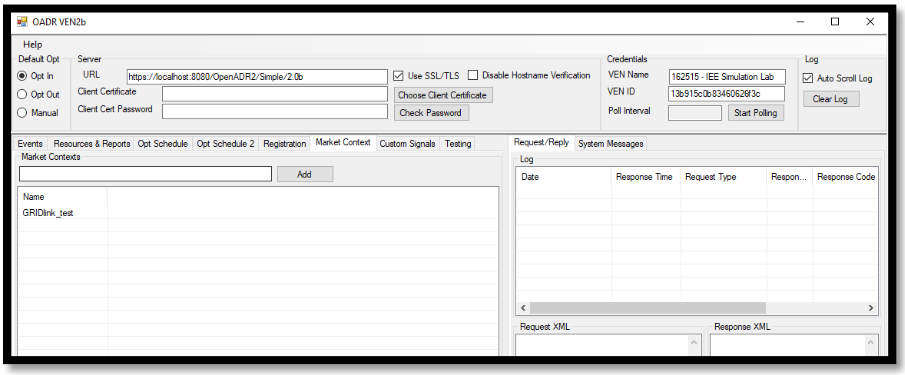


Figure 63: The gathered information implemented in the VEN software. Source: Own elaboration

Now create an event on the VTN platform (see section 3.4.4.1.3) and verify if the different message types are incoming. Before executing the event, make sure tab Market Context is filled in like Figure 63 otherwise there will be an error (Figure 64).

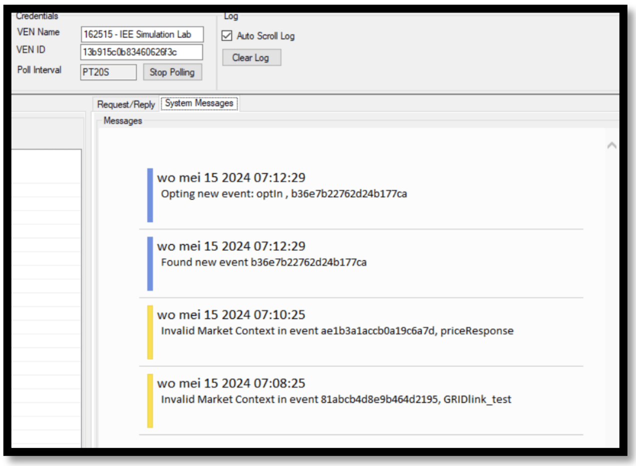


Figure 64: System messages showing error and found new event. Source: Own elaboration

If the "Registration" message types are receiving, then the VEN is online. A result can be seen on Figure 65, highlighted in red. More information about the message types can be found in section 2.5.4.4 "Messages and services according to OpenADR standard". The messages are expressed as a XML service and are visible as response and request payloads so they can be compared.

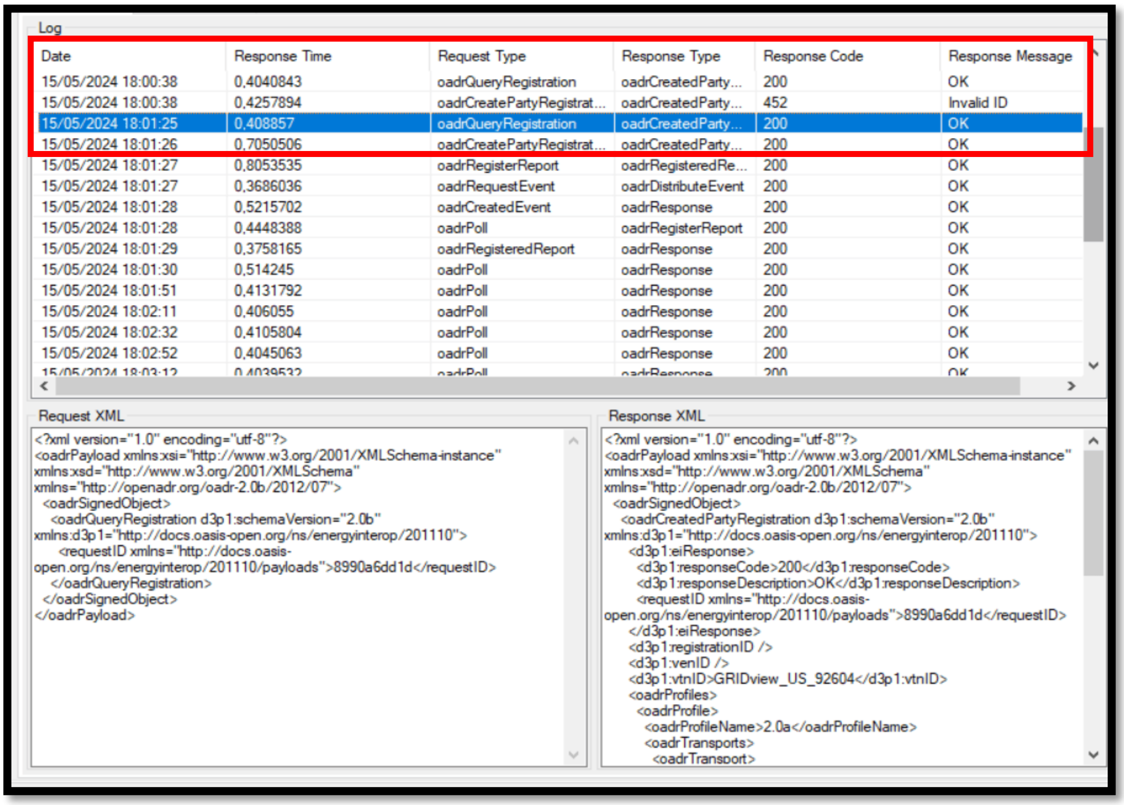


Figure 65: Log and communication history on the VEN software (OADR VEN2b). Source: Own elaboration

4.3.2 Checking the results when creating an event

When an event was created as followed on the procedure described in section 3.4.4.1.3, it is possible to verify this. One option is to analyse the LEDs of the GRIDlink hardware. (See section 3.4.5.2) Another option is using the VEN software (OADR VEN2b). Figure 66 shows the result of an active special event. This software can monitor the events and shows all the configurated parameters. (Figure 67, Figure 68, Figure 69 and Figure 70) Some examples of the configurated parameters are:

- The event has a **TargetID** for a VEN (13b915c0b83460626f3c) so only this VEN will respond and execute the event.
- The signal value is indicated as normal because **priority** is set to 0.
- The **signal type** is LOAD_CONTROL and set to value 11 (setpoint). It set load output to a relative value. The setting adjusts the load control based on the load controller's capabilities and maximum output.
- The **duration** of the event is 6 minutes.
- There is no **recovery** and **ramp up time** in this event.
- The **notification time** is 2 minutes.

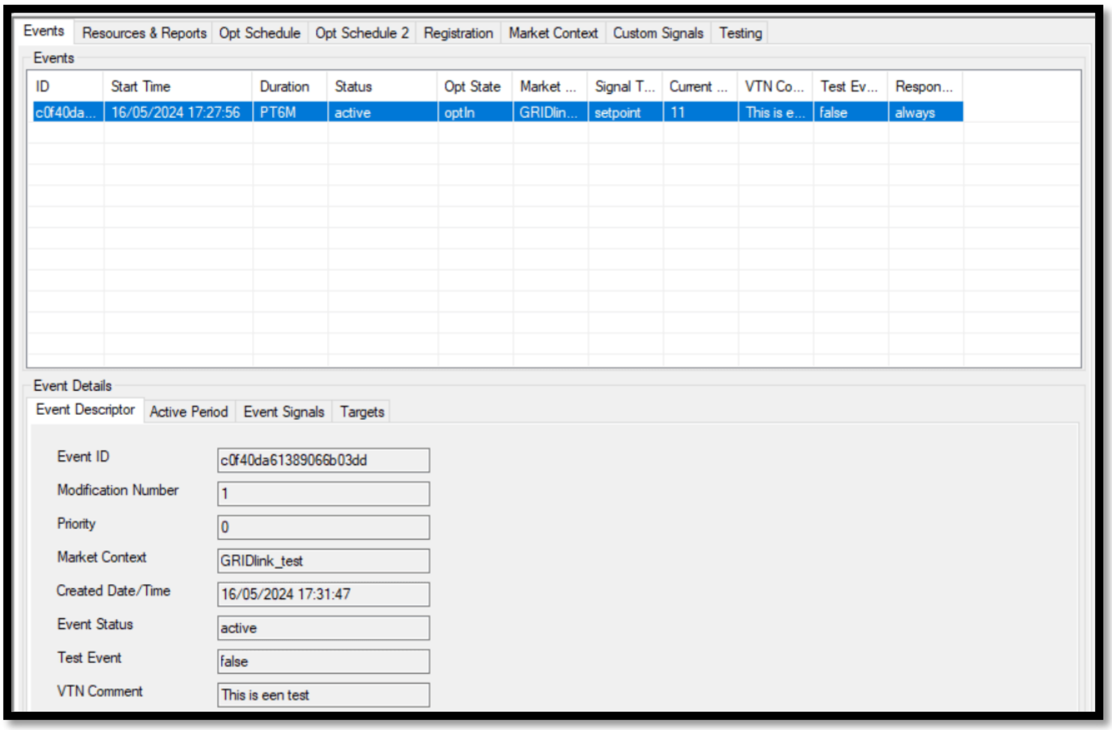


Figure 66: Monitoring a created event in the VEN software (OADR VEN2b). Source: Own elaboration

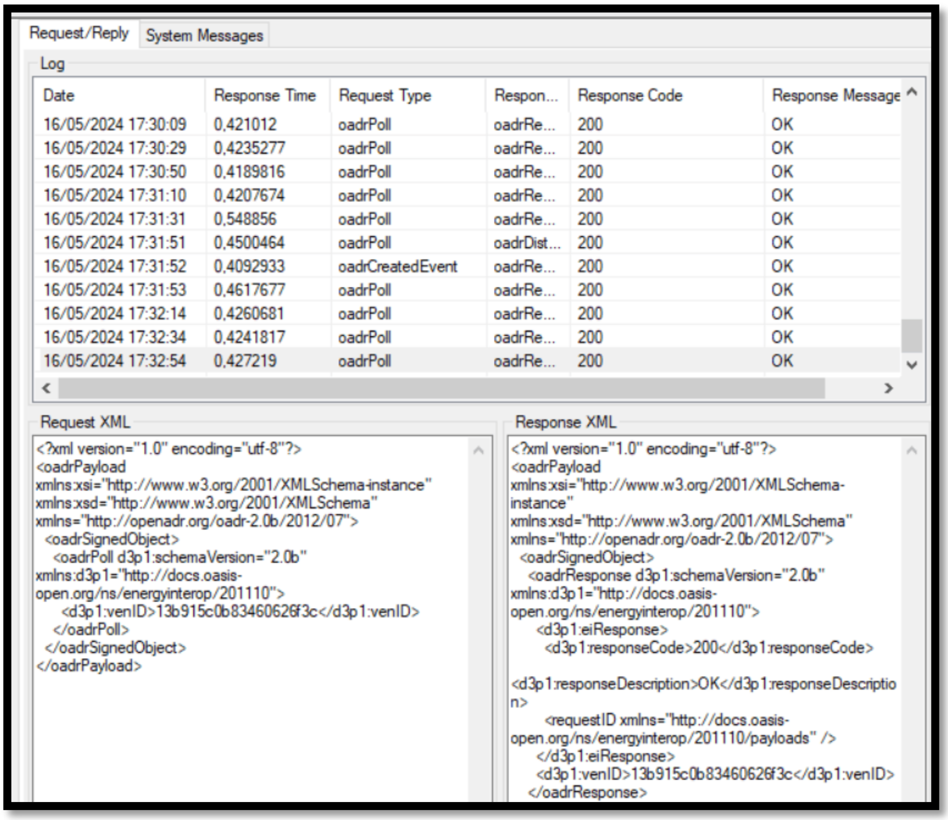


Figure 67: Communication history. Source: Own elaboration

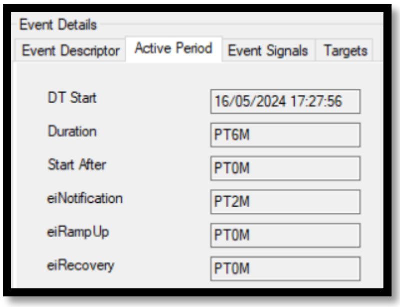


Figure 68: Event details - Active Period. Source: Own elaboration

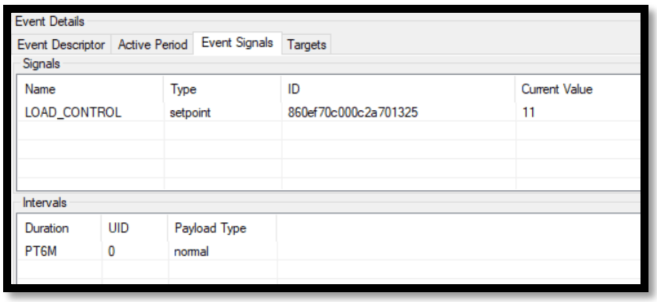


Figure 69: Event details – Event Signals and intervals. Source: Own elaboration

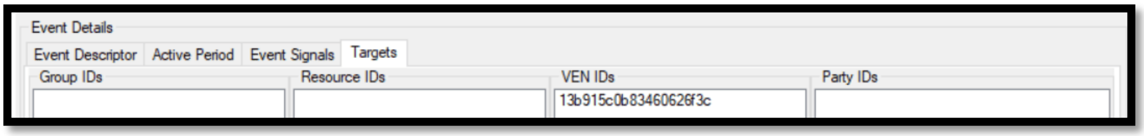


Figure 70: Event details - Targets. Source: Own elaboration

It is possible to see when event was pending and activated in a visual way, as demonstrated in Figure 71. Relay 1 (red) indicates a pending event, while Relay 2 (blue) signifies an activated event with a moderate signal. Both relays deactivate upon the event's completion. If Relay 3 is on, it denotes the event is activated with a special signal. Additionally, the graph can be shared via a "permalink." The platform currently supports exporting this data in .csv format, although importing data is not available at the time of writing.

Figure 71: Visualisation of an event; RED = RELAY 1; BLUE = RELAY 2; Source: Own elaboration

4.3.3 Test signal

To verify the functionality of the OpenADR hardware, test signals can be executed on the OpenADR platform of GRIDview NA. This section explains one situation of the creation and scheduling of a "Test Signal" to assess the responsiveness of a device or system to DR signals. Figure 72, Figure 73 and Figure 74 show the different phases of a DR event. In this case is the event a simple signal with a moderate level. Buttons "Send" and "Cancel" are available for each parameter, allowing users to transmit the signal to the device or abort the event, respectively.

Users can specify the duration the signal is pending before execution (Test Pending Minutes) and the duration of the signal itself (Set Duration). In this example is this respectively 15 and 20 minutes. The signal name is set as "SIMPLE" with a signal code of "101," which represents a specific signal name. A full list can be found in the table and further descriptions in Appendix 1. The signal type for a simple event is always “level,” as defined by the OpenADR specifications. The signal value is set to “1”, indicating a moderate signal that will trigger relay 2. The different signal values for simple events allows a user to define load shed strategies for each mode. Note that signal value “Special” do not correspond to any relay and would need to be defined by the user as the 2.0b specifications described. This relay 2 is connected to a DER controller for executing a DR program. Further analysis of how the connection to the DER controller works is beyond the scope of this thesis.

The "Relays" section displays the status of relays connected to DER controller, enabling the monitoring of their response to the DR signal. As earlier mentioned, it is possible to monitor and visualise the relays from the GRIDlink hardware. (Figure 75) This can be achieved by the button “Event History” shown on Figure 72, Figure 73 and Figure 74.

Table 14: List of Signal Names, Signal Types and Signal Values used in the OpenADR platform. Source: Own elaboration based on [109]

Signal Name	Signal Type	Signal Value for simple event
101 - SIMPLE	200 - none	1 - Simple Moderate
102 - ELECTRICITY_PRICE	201 - delta	2 - Simple High
103 - ENERGY_PRICE	202 - level	3 - Special* (refer to 2.0b specification)
104 - DEMAND_CHARGE	203 - multiplier	
105 - BID_PRICE	204 - price	
106 - BID_LOAD	205 - priceMultiplier	
107 - BID_ENERGY	206 - priceRelative	
108 - CHARGE_STATE	207 - product	
109 - LOAD_DISPATCH	208 - setpoint	
110 - LOAD_CONTROL		

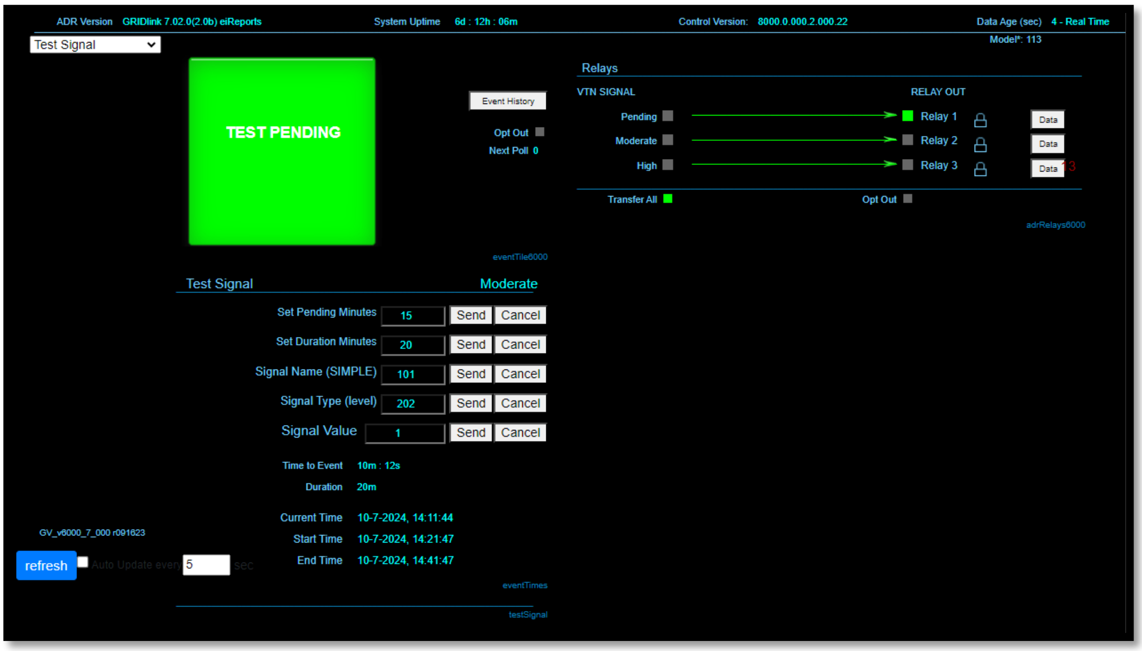


Figure 72: Simple signal with a moderate level – pending phase. Relay 1 is on. Source: Own elaboration

Figure 73: Simple signal with a moderate level – active phase. Relay 1 and Relay 2 is on. Source: Own elaboration

Figure 74: Simple signal with a moderate level – finished phase. Relay 1 and Relay 2 is off. Source: Own elaboration

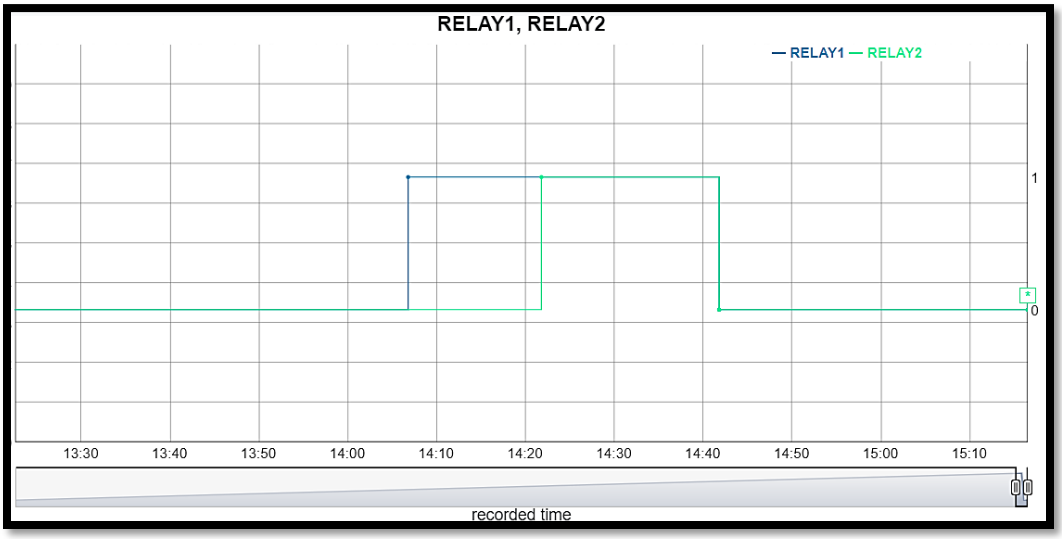


Figure 75: Visualisation of the used relays (ON = 1; OFF = 2) in function of the recorded time. Source: Own elaboration

4.4 Evaluation of the participation of the selected industrial factories in the Spanish balancing market

The simulation tool from DRIP is used for validating possible results when the company performed a flexibility audit. This section focuses on the results used from the simulation tool developed during the DRIP project. The results are for a DR action in tertiary regulation for load processes in food factories located in Spain. Section 4.1 details three balancing services in which DR programs can participate. However, due limited time, results are presented only for tertiary reserve, not secondary or replacement reserves. Also, some reserves are determined by individual bids, meaning the compensation received directly reflects the amount requested. This dynamic pricing structure makes it more complex to model realistic scenarios and accurately predict your cost functions for participation. For the simulation, there are a lot of inputs necessary as described in section 3.5. Table 15 gives an overview of where to find these data inputs.

Table 15: Where to find the data input for tertiary reserve, Spain. Source: Own elaboration

Type of data input	**Where to find the data input?**
Process load curve	Provided by a flexibility audit of the factory by an energy expert.
Price of the capacity band	No capacity band for tertiary reserve in Spain.
Delivery prices	https://www.esios.ree.es/en/analysis/677
Electricity contract prices	https://www.omie.es/en/market-results/monthly/daily-market/hourly-market?scope=monthly
CO_2 emission factors	https://demanda.ree.es/visiona/peninsula/demandaqh/total/
Technical specifications for delivery interruptions	Provided by a flexibility audit of the factory by an energy expert.
Flexibility costs for DR action.	Provided by a flexibility audit of the factory by an energy expert.

Note that some data inputs need to be prepared before implementing in the simulation tool. For example, determine electricity contract prices in Spain it is necessary to convert the day-ahead price using the information provided in Table 16 and Table 17.

Table 16: Conversion table from day-ahead price to final price for electricity contract. Source: Own elaboration based on the supply contract of the consumer.

6-period tarif	P1	P2	P3	P4	P5	P6
Multiplicative coefficient (A)	1,592	1,556	1,444	1,439	1,434	1,158
Additive coefficient (B) in EUR/MWh	43,230	34,841	22,102	15,487	7,898	8,694
Day-ahead market price from OMIE[7] in EUR/MWh	C	C	C	C	C	C
Final price for electricity contract in EUR/MWh	(A x C) + B	(A x C) + B	(A x C) + B	(A x C) + B	(A x C) + B	(A x C) + B

Table 17: Tariff with 6 different periods for energy and capacity. Source: Own elaboration based on [110]

Hour	Monday-Friday												Saterdays, Sundays and holidays
	January	February	March	April	May	June	July	August	September	October	November	December	
00.00-01:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
01:00-02:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
02:00-03.00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
03:00-04:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
04:00-05:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
05:00-06:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
06:00-07:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
07:00-08:00	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6	P6
08:00-09:00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
09:00-10.00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
10:00-11:00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
11:00-12:00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
12:00-13.00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
13:00-14.00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
14:00-15.00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
15:00-16.00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
16:00-17:00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
17:00-18.00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
18.00-19:00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
19:00-20.00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
20.00-21:00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
21:00-22:00	P1	P1	P2	P4	P4	P3	P1	P3	P3	P4	P2	P1	P6
22:00-23:00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6
23.00-00.00	P2	P2	P3	P5	P5	P4	P2	P4	P4	P5	P3	P2	P6

For each month and day type, the 3-hour period with the highest delivery prices is identified. The corresponding load processes are assumed to be shut down for this duration, in accordance with the terms of the Demand Response (DR) program participation agreement. Table 18 summarizes the selected periods for the DR actions. It is hard to conclude a general period of peak delivery prices due fluctuations of the marker prices.

[7] Data for C from https://www.omie.es/en/market-results/monthly/daily-market/hourly-market?scope=monthly

Table 18: The selected periods for the DR actions. Source: own elaboration

Month	April 2023	August 2023	November 2023	February 2024
Type 1 (Mondays)	06:30-09:30	05:15-8:15	04:00-07:00	16:30-19:30
Type 2 (Tuesdays, Wednesdays, Thursdays & Fridays)	19:30-22:30	19:30-22:30	11:00-14:00	13:00-16:00
Type 3 (Saturdays)	06:30-09:30	05:30-08:30	05:30-08:30	07:00-10:00
Type 4 (Sundays)	20:30-23:30	02:00-05:00	16:30-19:30	06:00-9:00

The results of the simulation tool are in table format and can be found in Appendix 6. The technical parameters of the DR actions for the different process groups can also be found here. It is based on this data for the simulation tool. The 4 scenarios (section 4.4.1 - 4.4.4) describes some graphs for using later in the economic, environmental and technical evaluation.

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4.4.1 Scenario 1: April 2023 Tertiary reserve

Figure 76 illustrates the average delivery prices (euro/MWh) in Spain for the month of April 2023, displayed as a function of the days of the month (percentage). Delivery price is the price that a customer receive when they reduce the power consumption during a DR event. The maximum value for this month is 291 euro/MWh end the minimum is 18 euro/MWh. 20% of the days of April 2023 has a value between 200 euro/MWh and 291 euro/MWh. 35% has a value between 100 euro/MWh and 18 euro/MWh. Around the midpoint (50% of the days), the delivery price is approximately 150 euro/MWh. The graph shows a roughly linear downward trend. For consumers relying on energy, this graph indicates a cost-saving opportunity if they can plan their DR action towards the day of the month when prices are higher. A general timing of peak delivery prices is difficult to pinpoint due fluctuations in market conditions.

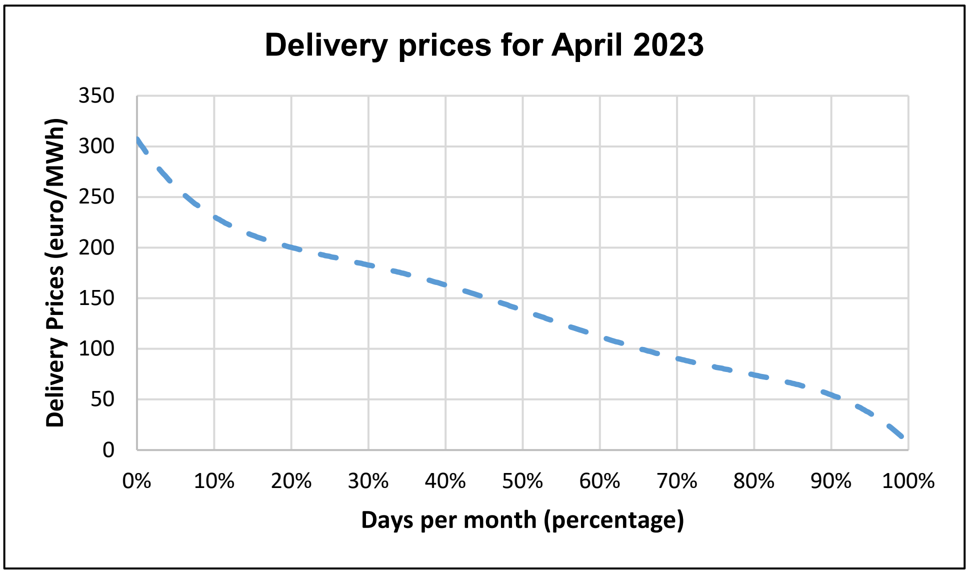

Figure 76: Average delivery prices (euro/MWh) in Spain for the month of April 2023, displayed as a function of the days of the month (percentage). Source: own elaboration

Figure 77 shows a summarized economic evaluation. The data includes total incomes (Sma + Ss + Pm), total costs (Cf + Ss-), and unitary net benefit (€/MWh). The unitary net benefit for the customer is calculated by the net benefit for the customer (Total incomes minus total costs) divided by the energy balance (energy reduced by the customers). For every parameter there are significant fluctuations. In Figure 78 there can also be concluded that the daily payments show considerable variability throughout the month. Due the variable delivery price and not in every hour of the day the TSO pays a delivery price, is the variability high. For example, on DR action of the 5th of April (see Table 18 which period the DR action was active = 19:30-22:30) there was no payment offered by the TSO. Further analysis could delve into other specific factors driving these trends to optimize operational strategies and financial performance.

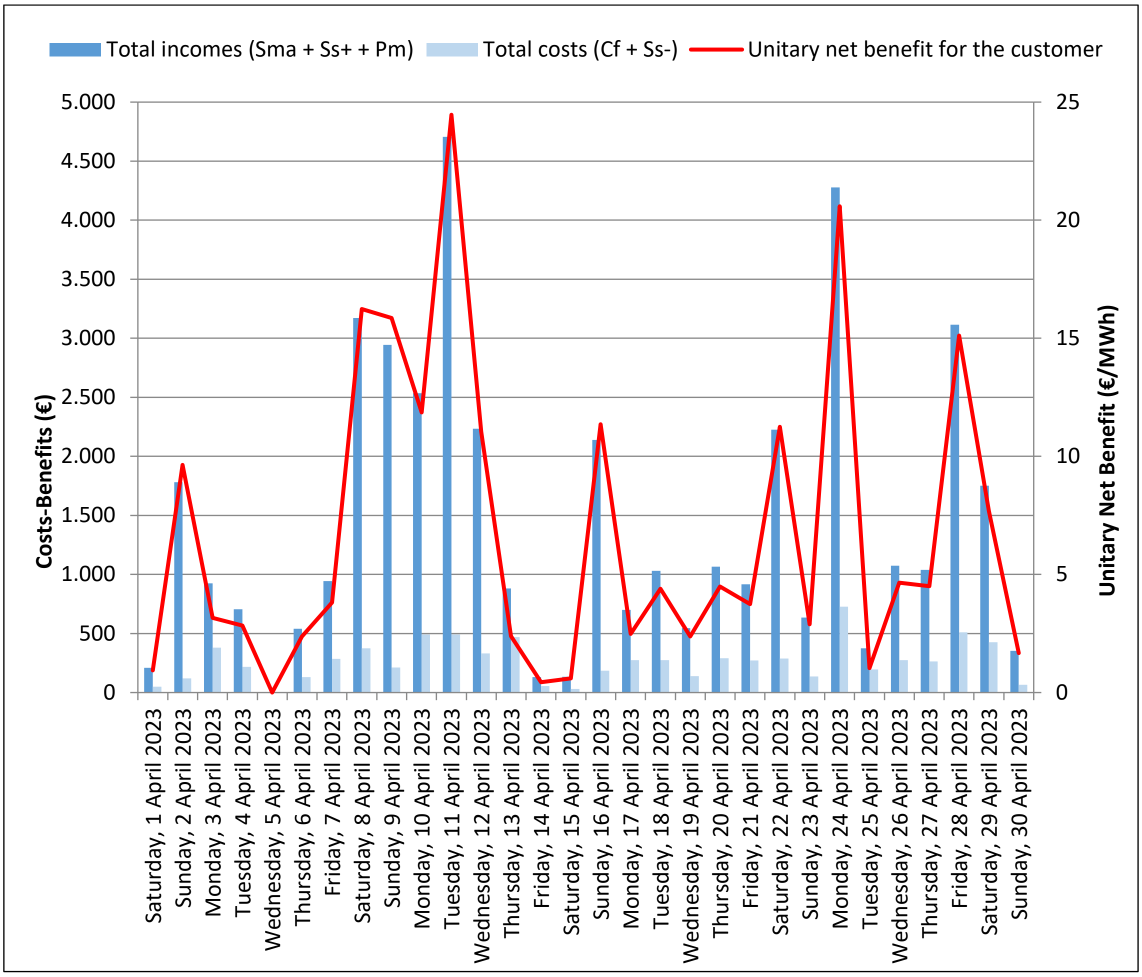

Figure 77: Daily financial performance and unitary net benefit for the customer over the month of April 2023. Source: own elaboration

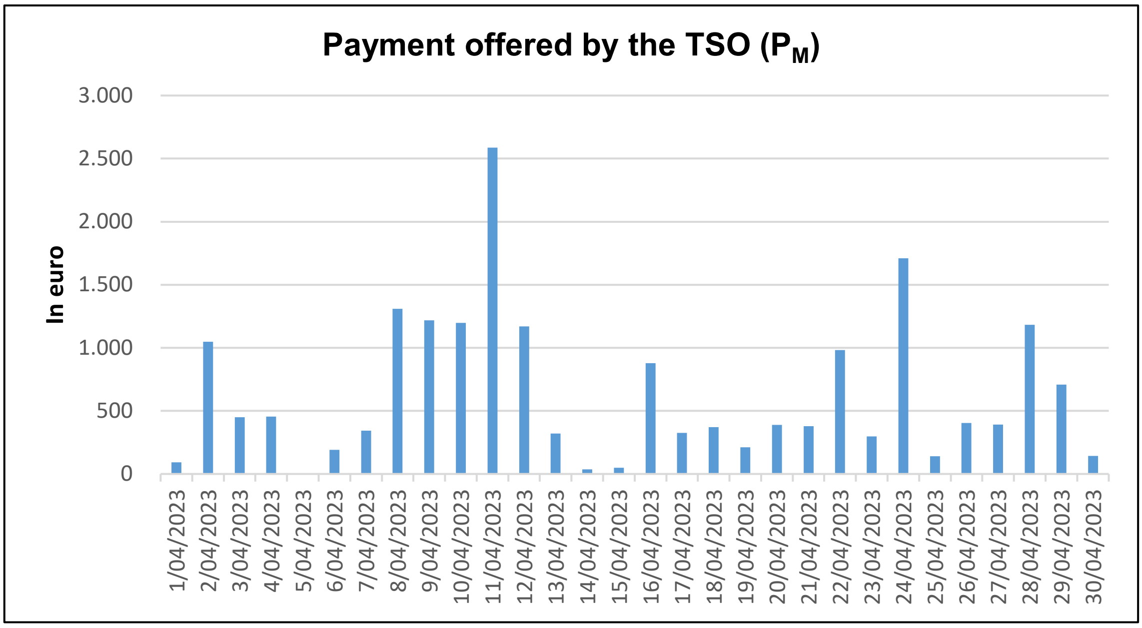

Figure 78: Payment offered by the TSO for the month April 2023. Source: own elaboration

Figure 79 displays the amount of saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month April 2023. The amount of energy saved fluctuates significantly throughout the month, with some days showing very high energy savings (above 10 000 kWh) while others have minimal or no savings. The same applies for the saved CO_2. As expected, there is a correlation between saved energy and reduced CO_2 emissions, highlighting the importance of energy conservation in mitigating climate change. Higher energy savings typically result in higher CO_2 savings. However, varying CO_2 emission factors must also be considered.

Be aware that the energy balance can also be negative when for a DR response was more energy needed. The saved CO_2 can also be negative if, during another time period, the CO_2 emission factor is higher. Analysed in the gathered data, most of the time is the CO_2 emission factor it lowest in the period between 11 AM and 6 PM due higher share of renewable resources compared to fossil energy resources.

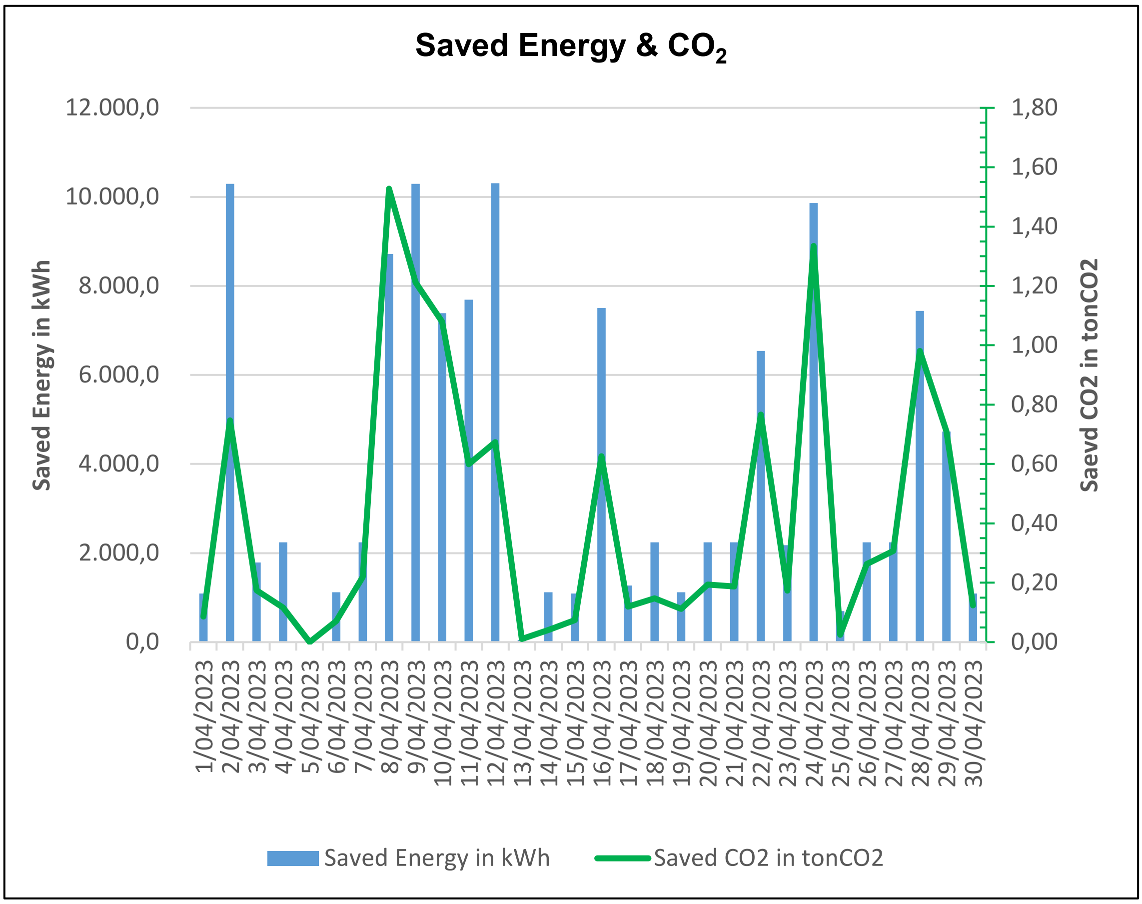

Figure 79: Saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month April 2023. Source: own elaboration

4.4.2 Scenario 2: August 2023 Tertiary reserve

Figure 80 illustrates the average delivery prices (euro/MWh) in Spain for the month of August 2023, displayed as a function of the days of the month (percentage). The maximum value for this month is 423 euro/MWh end the minimum is 94 euro/MWh. 30% of the days of August 2023 has a value between 350 euro/MWh and 423 euro/MWh. 30% has a value between 150 euro/MWh and 94 euro/MWh. Around the midpoint (50% of the days), the delivery price is approximately 250 euro/MWh. The graph shows a less linear downward trend then the scenario of 1 April 2023 (Figure 76). There is a significant drop in prices around 40% and 70%. This could be due to a sudden change in market conditions. There is a period of relative stability of the delivery prices between 40% and 70%. For consumers relying on energy, this graph indicates a cost-saving opportunity if they can plan their DR action towards the day of the month when prices are higher. A general timing of peak delivery prices is difficult to pinpoint due fluctuations in market conditions.

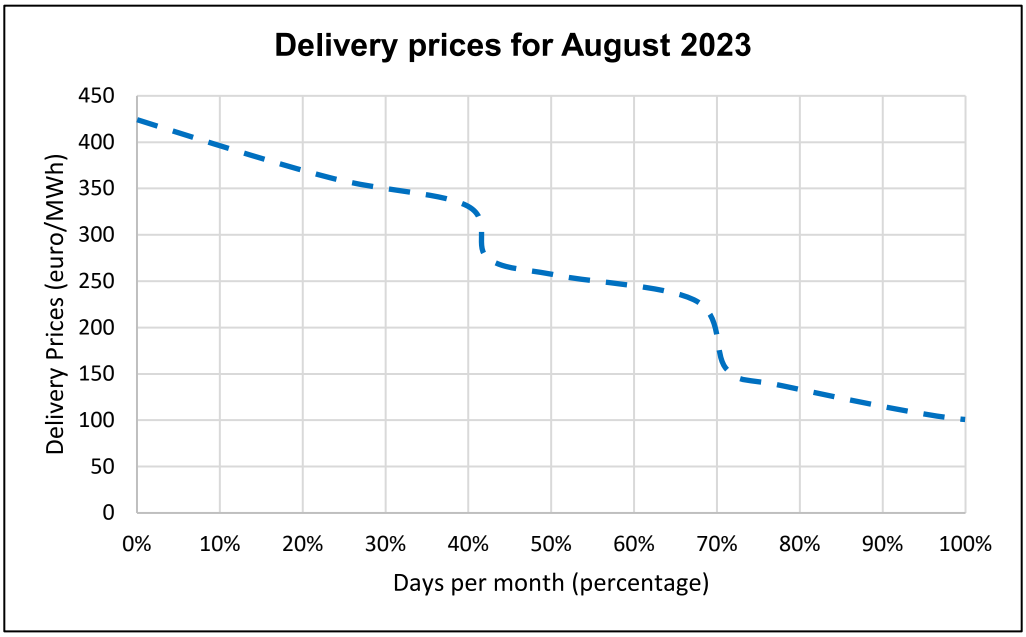

Figure 80: Average delivery prices (euro/MWh) in Spain for the month of August 2023, displayed as a function of the days of the month (percentage). Source: own elaboration

Figure 81 shows a summarized economic evaluation. The data includes total incomes (Sma + Ss + Pm), total costs (Cf + Ss-), and unitary net benefit (€/MWh). The unitary net benefit for the customer is calculated by the net benefit for the customer (Total incomes minus total costs) divided by the energy balance (energy reduced by the customers). For every parameter there are significant fluctuations. In Figure 82 there can also be concluded that the daily payments show considerable variability throughout the month. Due the variable delivery price and not in every hour of the day the TSO pays a delivery price, is the variability high. For example, on a DR action of the 29th of August (see Table 18 which period the DR action was active = 19:30-22:30) there was no payment offered by the TSO. Further analysis could delve into other specific factors driving these trends to optimize operational strategies and financial performance.

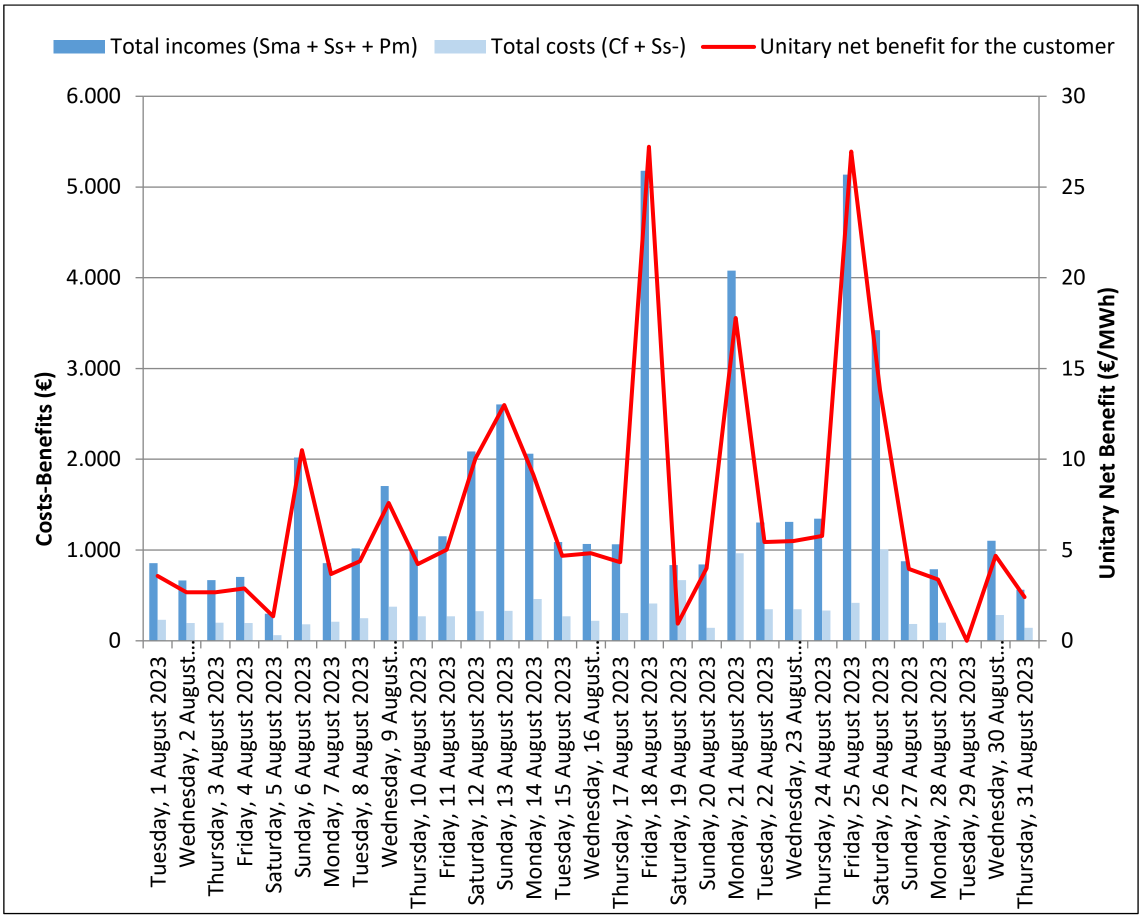

Figure 81: Daily financial performance and unitary net benefit for the customer over the month of August 2023. Source: own elaboration

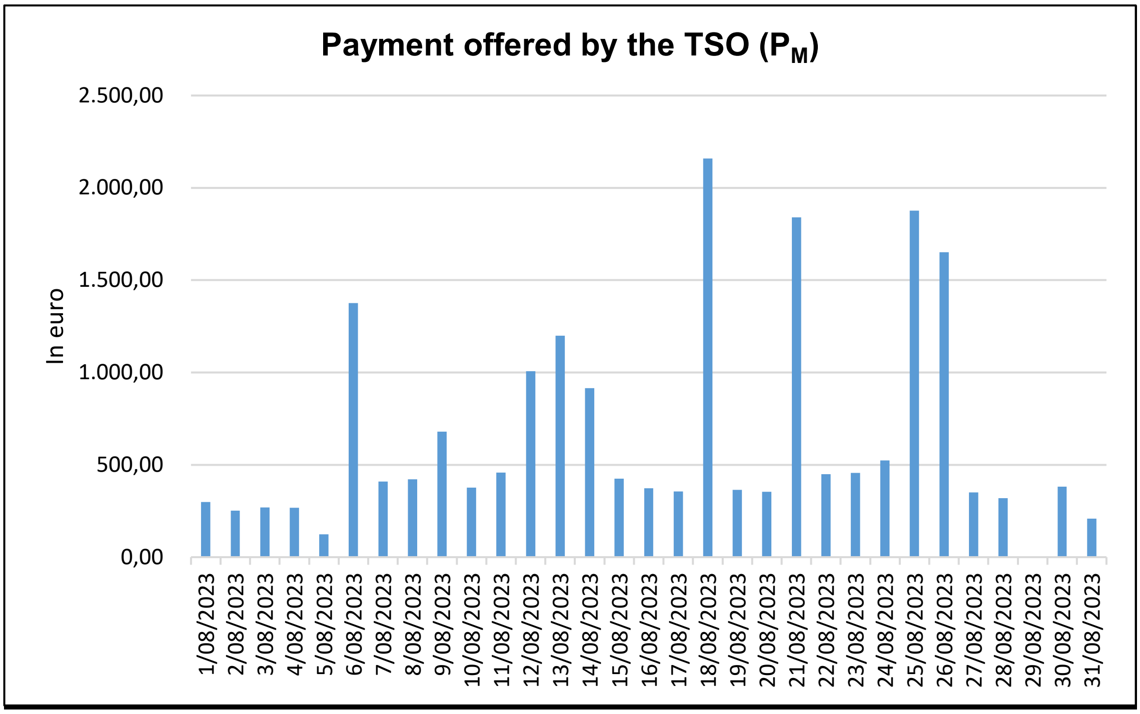

Figure 82: Payment offered by the TSO for the month August 2023. Source: own elaboration

Figure 83 displays the amount of saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month August 2023. The amount of energy saved fluctuates significantly throughout the month, with some days showing very high energy savings (above 12 000 kWh) while others have minimal or no savings. The same applies for the saved CO_2. As expected, there is a correlation between saved energy and reduced CO_2 emissions, highlighting the importance of energy conservation in mitigating climate change. Higher energy savings typically result in higher CO_2 savings. However, varying CO_2 emission factors must also be considered.

Be aware that the energy balance can also be negative when for a DR response was more energy needed. See Figure 83, 19th of August. The saved CO_2 can also be negative if, during another time period, the CO_2 emission factor is higher. Analysed in the gathered data, most of the time is the CO_2 emission factor it lowest in the period between 11 AM and 6 PM due higher share of renewable resources compared to fossil energy resources.

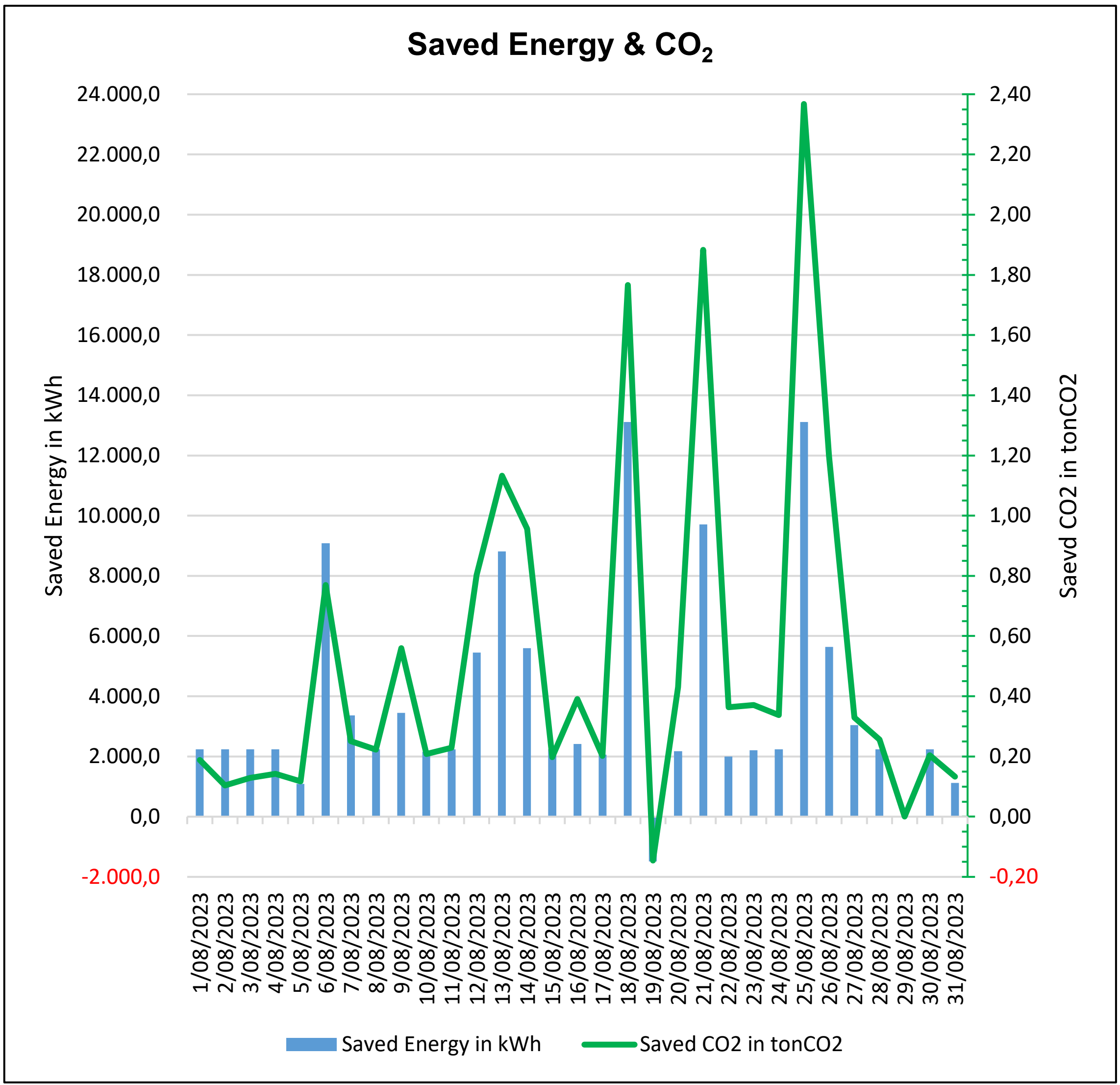

Figure 83: Saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month August 2023. Source: own elaboration

4.4.3 Scenario 3: November 2023 Tertiary reserve

Figure 84 illustrates the average delivery prices (euro/MWh) in Spain for the month of November 2023, displayed as a function of the days of the month (percentage). The maximum value for this month is 230 euro/MWh end the minimum is 9 euro/MWh. 25% of the days of November 2023 has a value between 130 euro/MWh and 230 euro/MWh. 20% has a value between 50 euro/MWh and 9 euro/MWh. Around the midpoint (50% of the days), the delivery price is approximately 80 euro/MWh. The graph does not show a linear decline and there are no significant drops in delivery prices. For consumers relying on energy, this graph indicates a cost-saving opportunity if they can plan their DR action towards the day of the month when prices are higher. A general timing of peak delivery prices is difficult to pinpoint due fluctuations in market conditions.

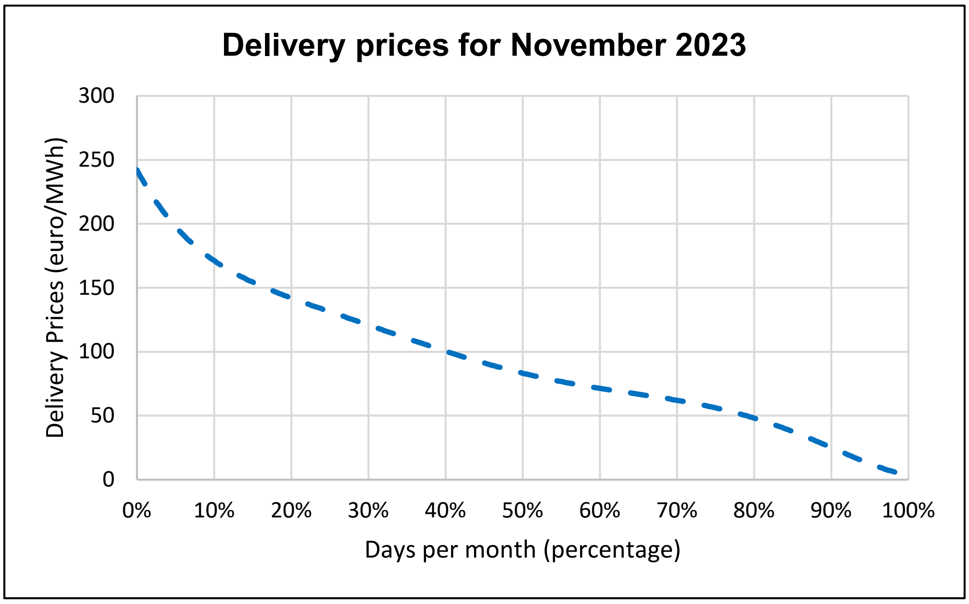

Figure 84: Average delivery prices (euro/MWh) in Spain for the month of November 2023, displayed as a function of the days of the month (percentage). Source: own elaboration

Figure 85 shows a summarized economic evaluation. The data includes total incomes (Sma + Ss + Pm), total costs (Cf + Ss-), and unitary net benefit (€/MWh). The unitary net benefit for the customer is calculated by the net benefit for the customer (Total incomes minus total costs) divided by the energy balance (energy reduced by the customers). For every parameter there are significant fluctuations. In Figure 86 there can also be concluded that the daily payments show considerable variability throughout the month. Due the variable delivery price and not in every hour of the day the TSO pays a delivery price, is the variability high. For example, on a DR action of the 7th of November (see Table 18 which period the DR action was active = 11:00-14:00) there was no payment offered by the TSO. Further analysis could delve into other specific factors driving these trends to optimize operational strategies and financial performance.

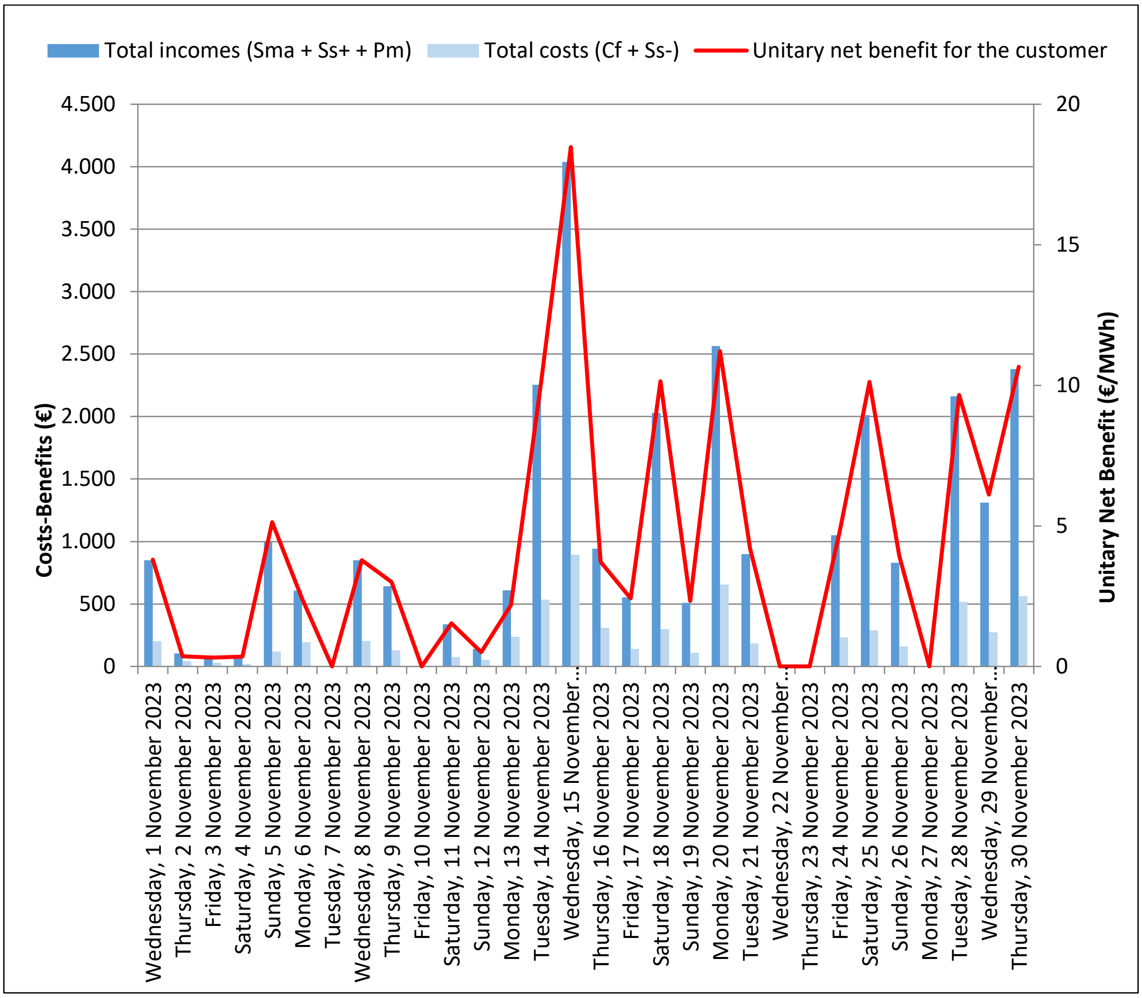

Figure 85: Daily financial performance and unitary net benefit for the customer over the month of November 2023. Source: own elaboration

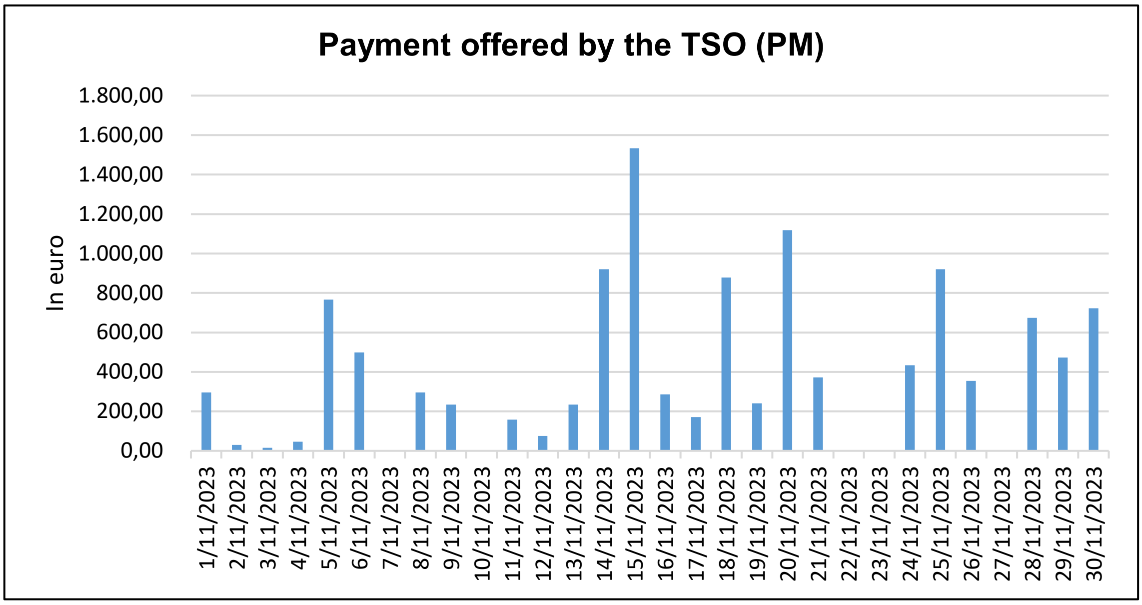

Figure 86: Payment offered by the TSO for the month November 2023. Source: own elaboration

Figure 87 displays the amount of saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month November 2023. The amount of energy saved fluctuates significantly throughout the month, with some days showing very high energy savings (above 9 000 kWh) while others have minimal or no savings. The same applies for the saved CO_2. As expected, there is a correlation between saved energy and reduced CO_2 emissions, highlighting the importance of energy conservation in mitigating climate change. Higher energy savings typically result in higher CO_2 savings. However, varying CO_2 emission factors must also be considered.

Be aware that the energy balance can also be negative when for a DR response was more energy needed. The saved CO_2 can also be negative if, during another time period, the CO2 emission factor is higher. See Figure 87, 2nd of November. Analysed in the gathered data, most of the time is the CO_2 emission factor it lowest in the period between 11 AM and 6 PM due higher share of renewable resources compared to fossil energy resources.

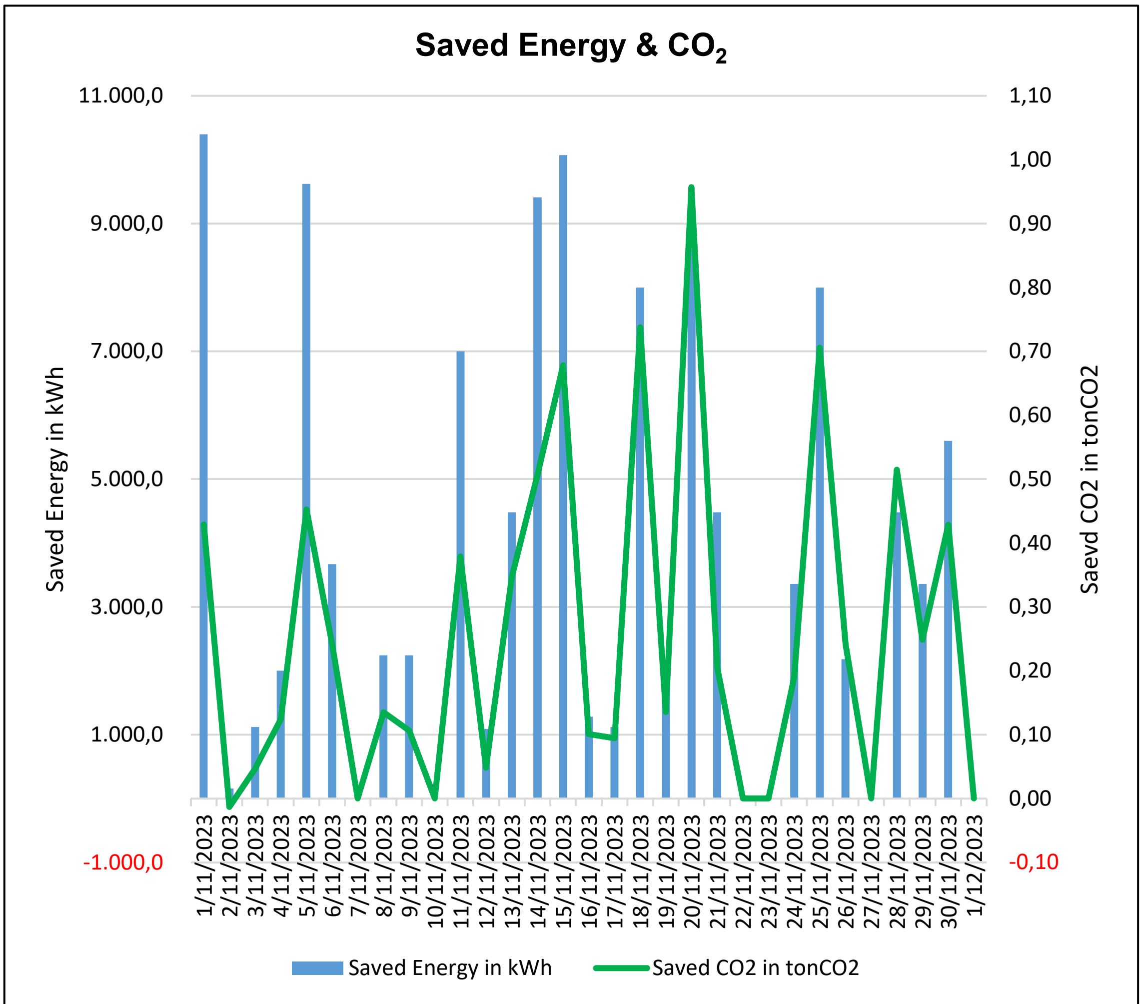

Figure 87: Saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month November 2023. Source: own elaboration

4.4.4 Scenario 4: February 2024 Tertiary reserve

Figure 88 illustrates the average delivery prices (euro/MWh) in Spain for the month of February 2024, displayed as a function of the days of the month (percentage). The maximum value for this month is 170 euro/MWh end the minimum is 12 euro/MWh. 20% of the days of November 2023 has a value between 120 euro/MWh and 170 euro/MWh. 20% has a value between 20 euro/MWh and 12 euro/MWh. Around the midpoint (50% of the days), the delivery price is approximately 38 euro/MWh. The graph does not show a linear decline (more quadratic) and there are no significant drops in delivery prices. For consumers relying on energy, this graph indicates a cost-saving opportunity if they can plan their DR action towards the day of the month when prices are higher. A general timing of peak delivery prices is difficult to pinpoint due fluctuations in market conditions.

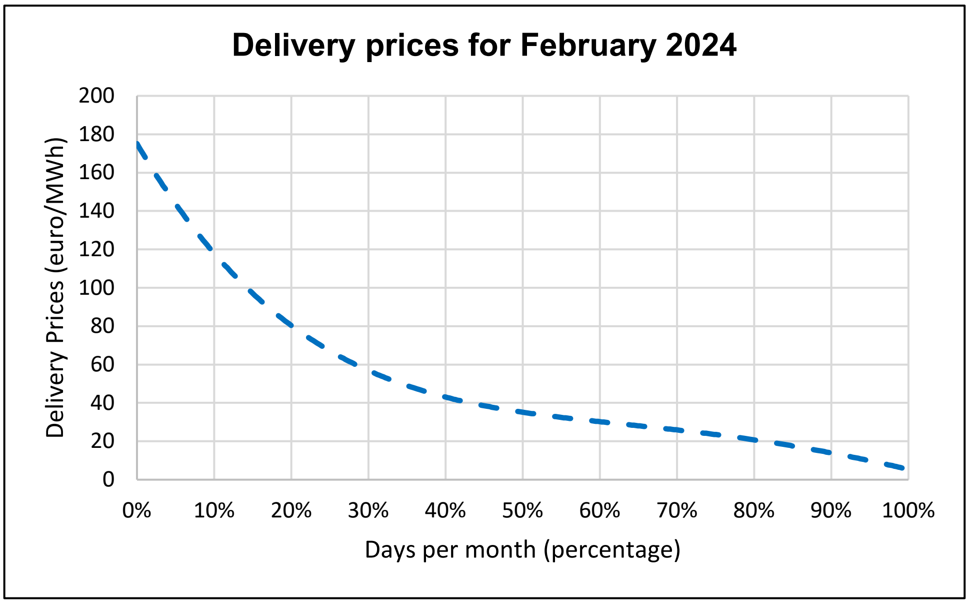

Figure 88: Average delivery prices (euro/MWh) in Spain for the month of February 2024, displayed as a function of the days of the month (percentage). Source: own elaboration

Figure 89 shows a summarized economic evaluation. The data includes total incomes (Sma + Ss + Pm), total costs (Cf + Ss-), and unitary net benefit (€/MWh). The unitary net benefit for the customer is calculated by the net benefit for the customer (Total incomes minus total costs) divided by the energy balance (energy reduced by the customers). For every parameter there are significant fluctuations. In Figure 90 there can also be concluded that the daily payments show considerable variability throughout the month. Due the variable delivery price and not in every hour of the day the TSO pays a delivery price, is the variability high. For example, on a DR action of the 6th of February (see Table 18 which period the DR action was active = 13:00-16:00) there was no payment offered by the TSO. Further analysis could delve into other specific factors driving these trends to optimize operational strategies and financial performance.

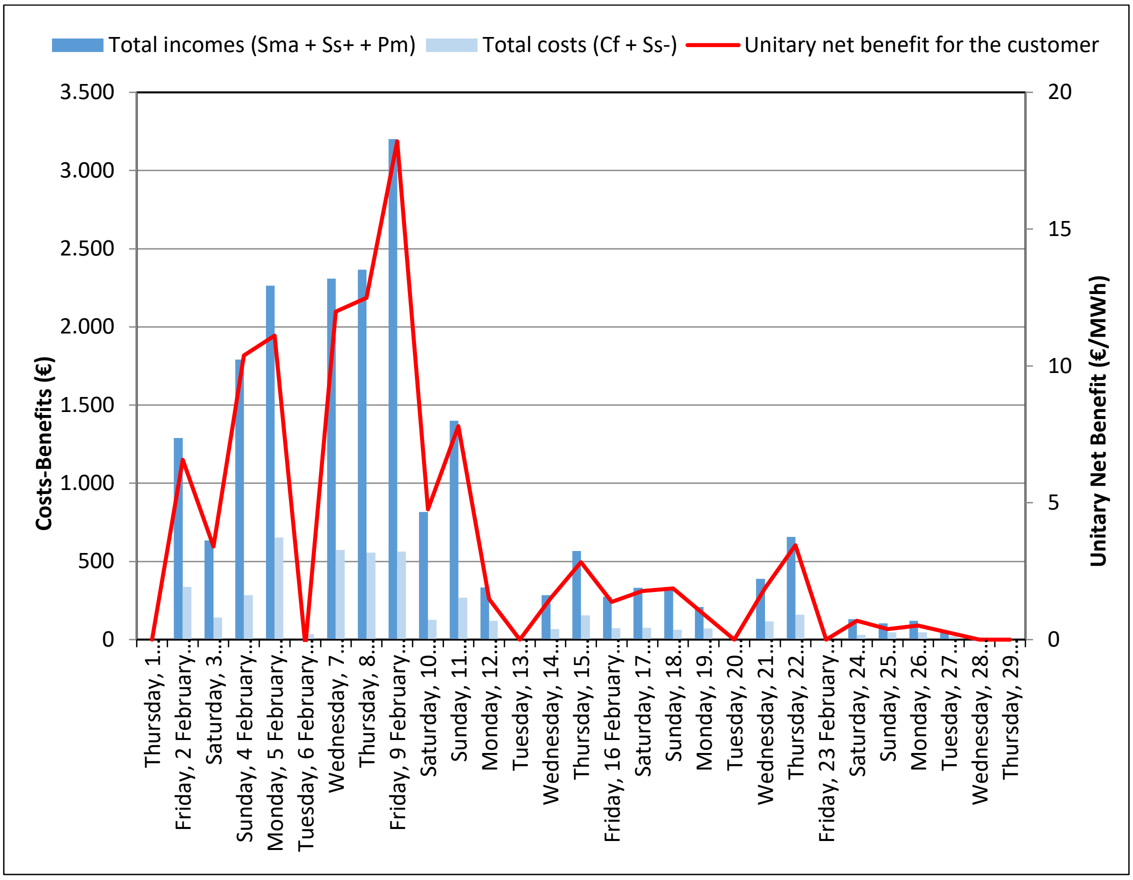

Figure 89: Daily financial performance and unitary net benefit for the customer over the month of February 2024. Source: own elaboration

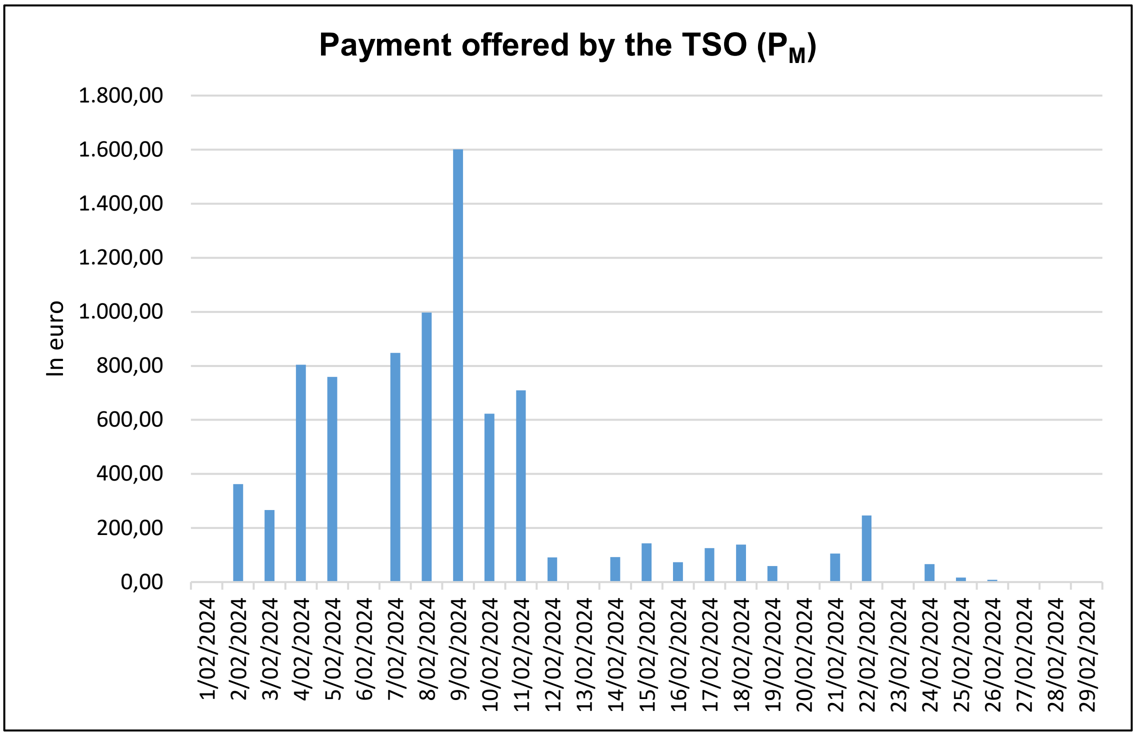

Figure 90: Payment offered by the TSO for the month February 2024. Source: own elaboration

Figure 91 displays the amount of saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month February 2024. The amount of energy saved fluctuates significantly throughout the month, with some days showing very high energy savings (above 8 000 kWh) while others have minimal or no savings. The same applies for the saved CO_2. There is a correlation between saved energy and reduced CO_2 emissions, highlighting the importance of energy conservation in mitigating climate change. Higher energy savings typically result in higher CO_2 savings. However, varying CO_2 emission factors must also be considered.

Be aware that the energy balance can also be negative when for a DR response was more energy needed. See Figure 91, 6th of February. The saved CO_2 can also be negative if, during another time period, the CO2 emission factor is higher. Analysed in the gathered data, most of the time is the CO_2 emission factor it lowest in the period between 11 AM and 6 PM due higher share of renewable resources compared to fossil energy resources.

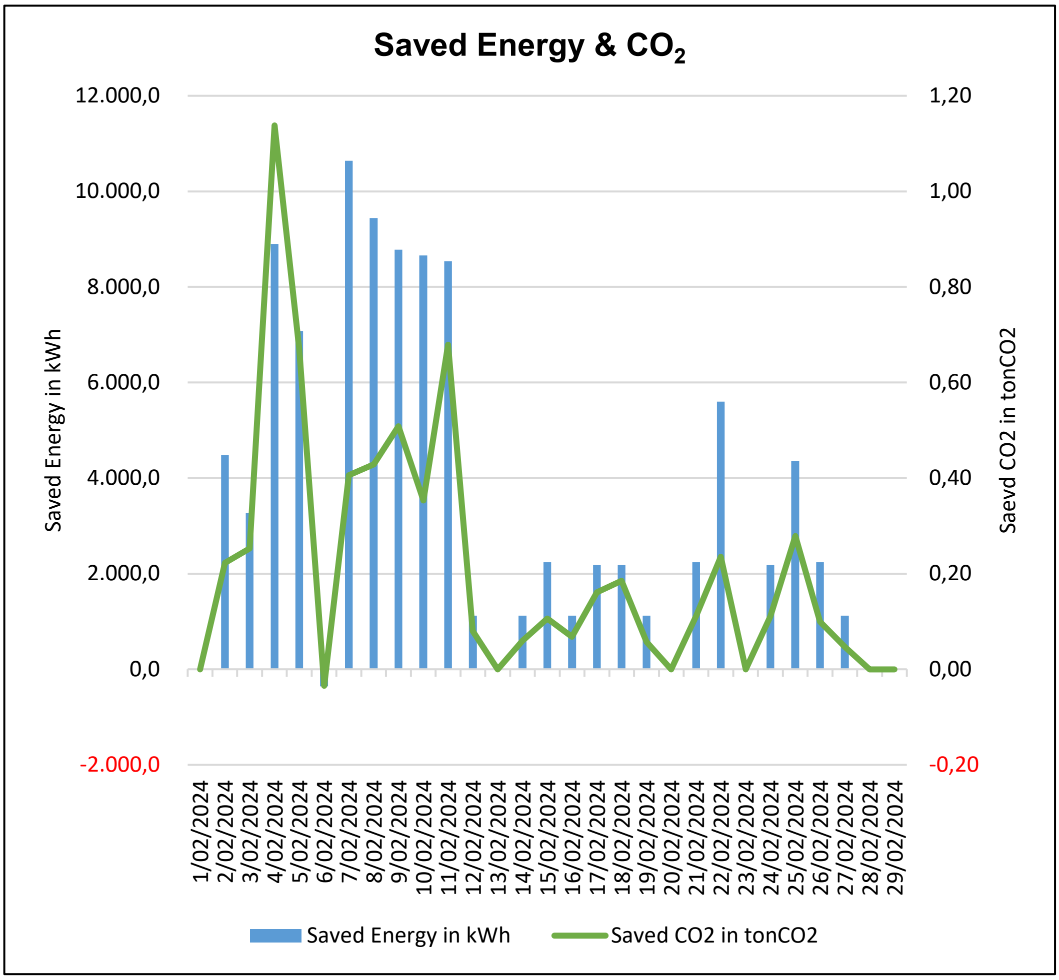

Figure 91: Saved energy (in kWh) and the corresponding saved CO_2 (in tons of CO_2) for the month February 2024. Source: own elaboration

4.4.5 Evaluating the 4 scenarios

Table 19: Overview of the results of the simulation tool developed during the DRIP project for the four months. Source: own elaboration

Month	Initial consumption	Final consumption	Energy balance	CO_2 balance	Economical energy balance (S_S)	Minimum payment required by customers (P_M^{min})	Payment offered by the TSO (P_M)	Margin of decission (P_M-P_M^{min})	TOTAL COSTS ($C_f + S_s^-$)	TOTAL INCOMES ($S_{MA} + S_S^+ + P_M$)	NET BENEFIT FOR THE CUSTOMER
	kWh	*kWh*	*kWh*	*tonCO₂*	*euro*	*euro*	*euro*	*euro*	*euro*	*euro*	*euro*
April 2023	10.347.771,00	10.228.710,94	119.060,00	12,70	16.535,67	341,99	18.981,60	18.639,61	7.958,48	43.082,53	35.124,05
August 2023	12.107.864,00	11.991.363,90	116.500,00	16,10	18.123,13	186,30	20.145,12	19.958,83	9.817,23	47.706,05	37.888,82
November 2023	12.176.302,00	12.059.801,69	116.500,00	8,04	10.996,66	61,25	11.751,45	11.690,20	6.471,56	28.836,16	22.364,60
February 2024	11.042.330,00	10.944.079,91	98.250,00	6,22	7.456,20	56,10	8.140,86	8.084,76	4.577,62	19.854,33	15.276,71

From Table 19 and the graphs from the 4 scenarios (section 4.4.1 - 4.4.4) some general conclusion are made. Figure 92 illustrates the average delivery prices (euro/MWh) in Spain for the 4 months, displayed as a function of the days of the month (percentage). February 2024 shows the lowest prices across all percentages of days in a month, while August 2023 has the highest. August 2023 stands out with notable price drops around the 40% mark and the 70% mark. The data suggests that consumers can benefit from flexible delivery scheduling if they can change their load curves more toward the higher delivery prices, but a general timing of peak delivery prices is difficult to pinpoint due fluctuations in market conditions. There is no same average delivery price for the four months, so this again confirms the fluctuation. The graph does not provide information on the underlying factors driving these price changes. Typical factors influencing these price changes could be energy market fluctuations, seasonal factors and supply and demand dynamics.

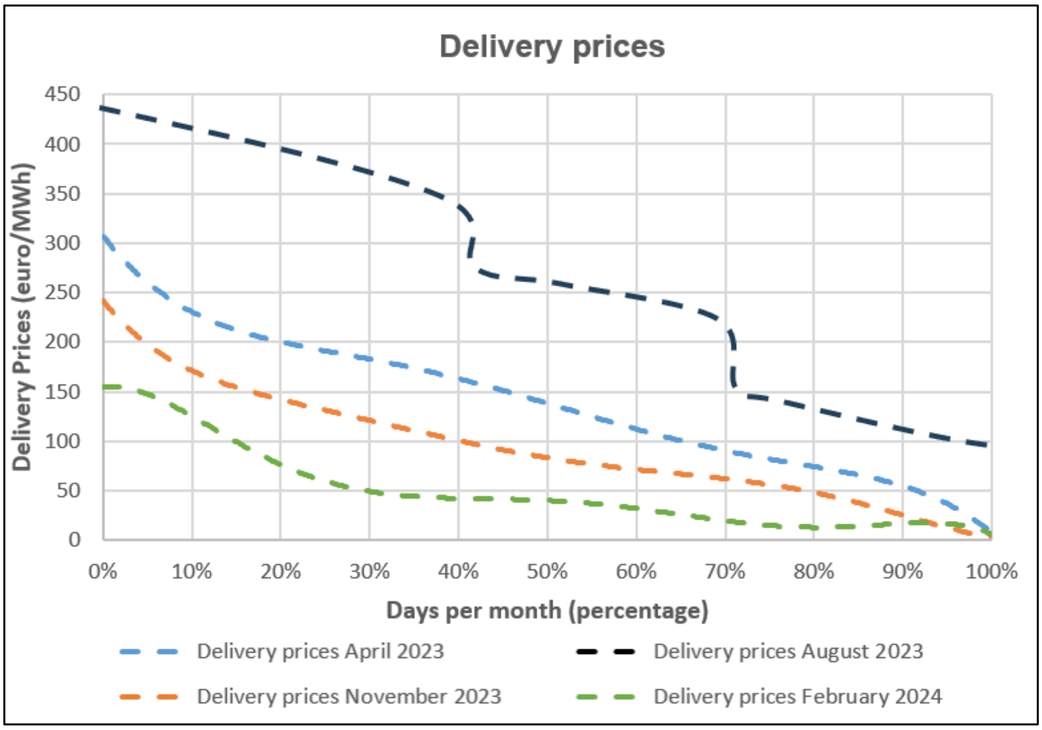

Figure 92: Average delivery prices (euro/MWh) in Spain for the four scenarios, displayed as a function of the days of the month (percentage). Source: own elaboration

4.4.5.1 Technical

For a good technical evaluation is individual load processes from each factory necessary, as well as the total load curve. The simulation tool enables visualization of load curves for different processes. Figure 93 and Figure 94 summarising typical scenarios during DR action execution. Further examples and results are available in Appendix 6.

Figure 93 and Figure 94 are organized into three columns. The first illustrates load shifting, where additional energy is required after finishing the DR action for restoring the process like a freezer. The cost is clearly visible (red) on Figure 94. The second column demonstrates load curtailment or shedding, involving no extra energy consumption before or after the DR action. Un example can be shut down a non-essential process line. The third column represents scenarios without interruption, as no payment was offered by the TSO.

The first two scenarios highlight how the DR action aims to activate when TSO payments are highest. Payments from the TSO can be an important factor, depending on the reserve market and country. The factory decides when it is feasible to activate a DR, which must be clearly stated in the agreement for participating in the DR program. An energy flexibility audit can be helpful for making the right decisions.

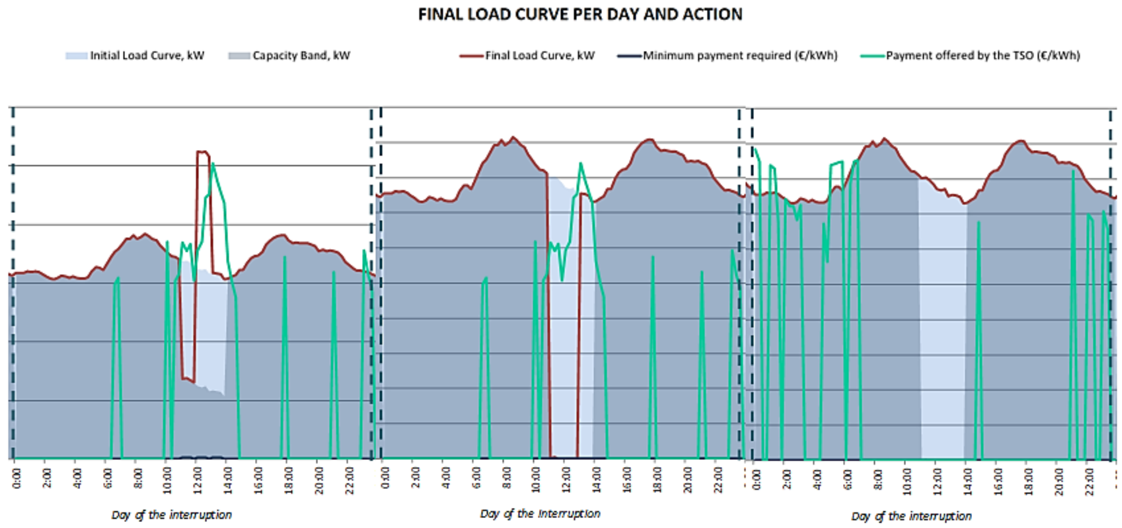

Figure 93: Final load curves per action from three typical DR scenarios. Source: own elaboration

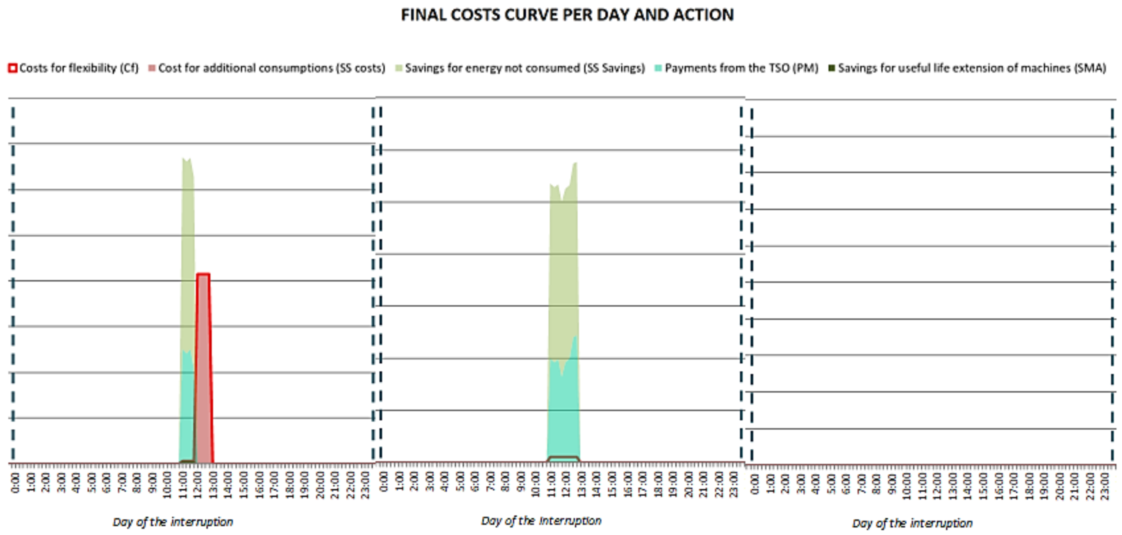

Figure 94: Final costs curves per action from three typical DR scenarios. Source: own elaboration

The energy balance is the difference between the Energy not consumed (S_{s+}) and Additional energy consumed (S_{s-}). When the energy balance is positive then it means energy reduced by customers. When negative it means an increasing. Figure 95 shows for the four scenarios all positive energy balance. Be in mind that these results can be too optimistic due the chosen optimal DR actions.

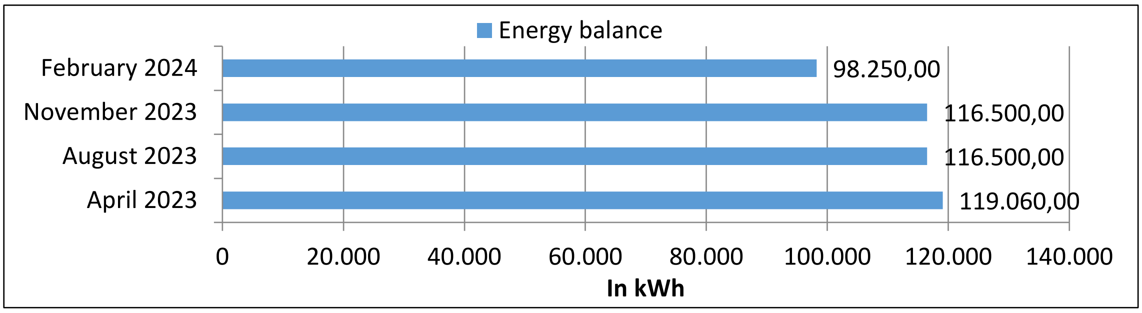

Figure 95: Energy balance for the four scenarios. Source: own elaboration

4.4.5.2 Economic

Economic impact for the customer includes the electricity contract, the cost of flexibility adjustments (See also section 3.5.2.3 Unitary action cost), and fluctuations in the energy market prices (for example delivery prices, see section 4.4.5). For the system is economic impact calculated by the difference between the payments offered by the TSO and the minimum required benefit by the customers. This "margin of decision" is transformed to an "unitary margin" due "margin of decision" divided by "energy reduced by customers". Table 20 and Figure 96 gives an overview for the economic impact for the system.

Table 20: Parameters for the economic impact for the system, calculating Unitary margin. Source: own elaboration

Month	Energy reduced by customers	Required benefit by customers	Payment offered by the TSO	Margin of decision	Unitary margin
	kWh	€	€	€	€/MWh
April 2023	172.275	342	18.982	18.640	108
August 2023	175.075	186	20.145	19.959	114
November 2023	170.313	61	11.751	11.690	69
February 2024	144.913	56	8.141	8.085	56
TOTAL	662.575	646	59.019	58.373	87

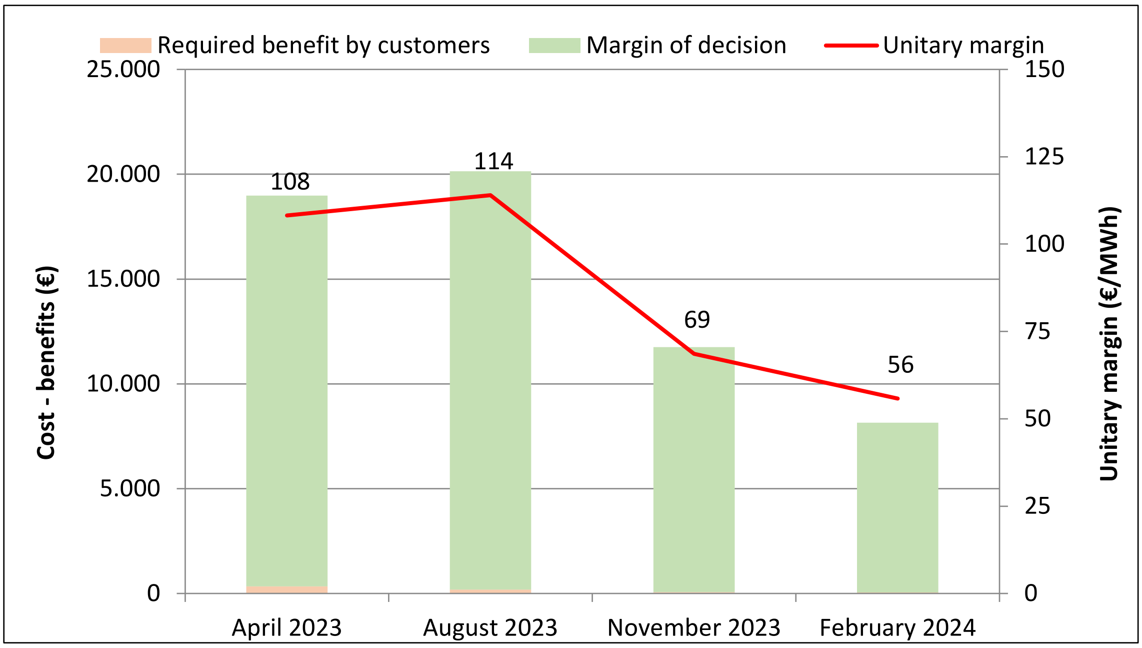

Figure 96: Economic impact for the system. Source: own elaboration

Take in mind that required benefit for the customer will be higher than the results in Figure 96 because some factors can be inaccurate implemented in the simulation tool. The required benefit for the customer depends on the costs incurs when a DR action is performed and the expected benefit of the customer. These variables are difficult to determine exactly.

Figure 101 illustrates the total payment offered by the TSO per month and the net benefit for the customer. The lowest payment and net benefit were observed in February 2024. The “Net benefit for the customer” can obtained by “Total incomes” minus “Total Costs”. The total payment offered by the TSO depends on the delivery prices for the tertiary reserve in Spain and are highly variable. Changes in market conditions or regulatory policies might influence this parameter. The highest payment by the TSO and the most significant net benefit for the customer occurred in August 2023. The lowest payment and net benefit were observed in February 2024. A more in-depth analysis is needed to pinpoint the exact causes of these variations.

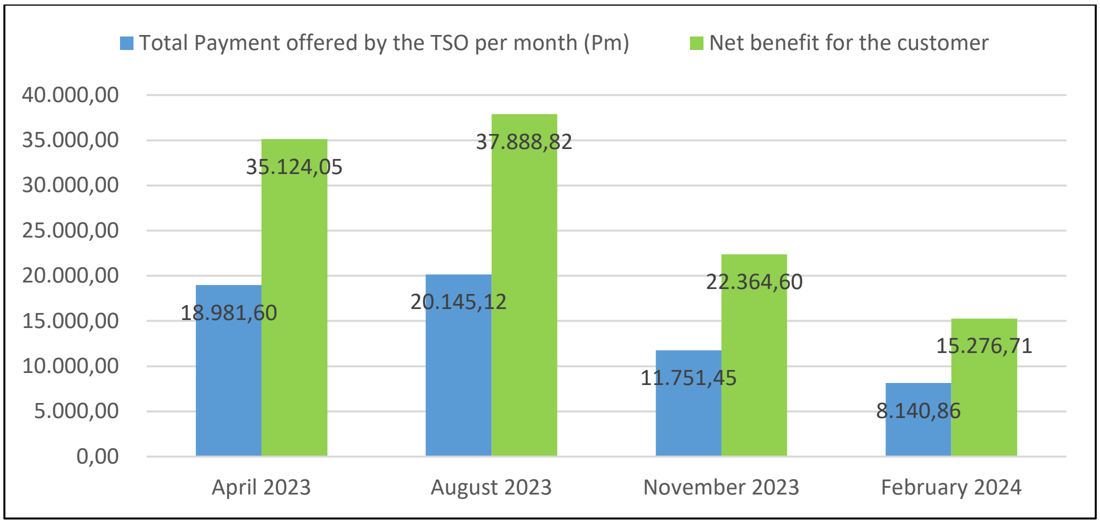

Figure 97: Total payment offered by TSO per month and net benefit for the customer. Source: own elaboration

Another economic parameter is the Unitary net benefit for the customer. It represents the profitability of a DR action independently of its interrupted power and the number of interrupted hours. It is calculated by dividing “Net benefit for the customer” with Energy not consumed. The “Net benefit for the customer” can obtained by “Total incomes” minus “Total Costs”. Table 11 and Figure 98 clarify this. The maximum unitary benefit for the customer would be obtained in August 2023 due the high share of “Total incomes” compared to the “Total costs”. It peaks at 216,41 euro/MWh while 105,42 euro/MW is the lowest value. Despite the costs reducing slightly after August 2023, the drop in incomes is more significant, leading to lower net benefits for the customer.

Table 21: Parameters for calculating Unitary Net benefit for the customer. Source: own elaboration

Month	Total incomes (S_{MA} + S_{S+} + P_M) in euro	Total costs (C_f + S_{S-}) in euro	Net benefit for the customer in euro	Energy not consumed S_{S+} in kWh	Unitary Net benefit for the customer in euro/MWh
April 2023	43.082,53	7.958,48	35.124,05	172.275,00	203,88
August 2023	47.706,05	9.817,23	37.888,82	175.075,00	216,41
November 2023	28.836,16	6.471,56	22.364,60	170.312,50	131,32
February 2024	19.854,33	4.577,62	15.276,71	144.912,50	105,42
TOTAL	139.479,07	28.824,89	110.654,18	662.575,00	164,26

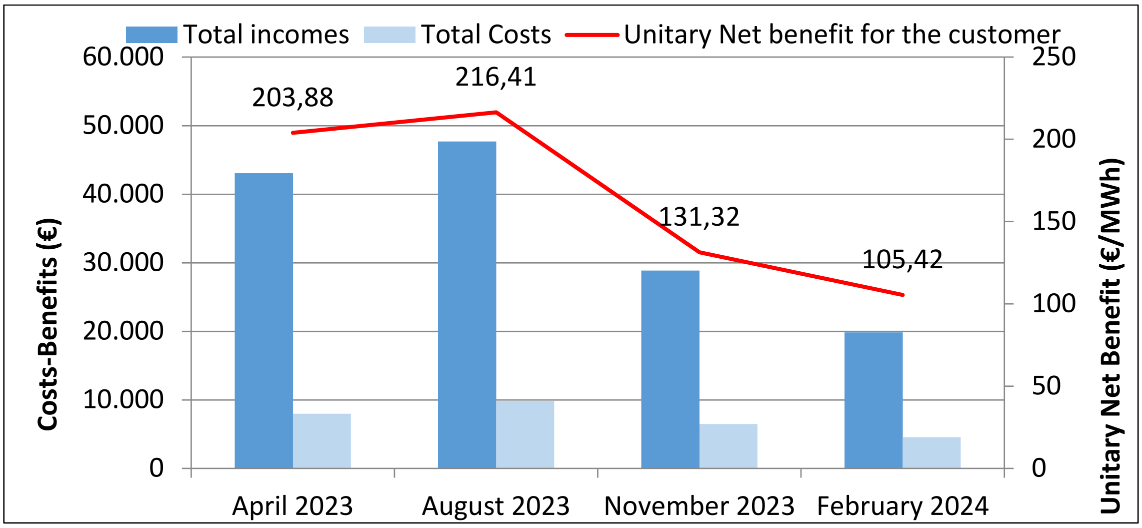

Figure 98: Economic Impact for the customer. Source: own elaboration

A last important economic parameter is deciding the cost benefit with a payback time. Remark that used input is estimated and is wurst case scenario. Be aware that some parts from the total costs are not implemented in the simulation tool like costs of control and monitoring (= a direct cost see section Unitary action cost 3.5.2.3).

The investment is determined as follows. There are every time four processes used in eight factories:

- Each process requires an OpenADR device (VEN) at a cost of 2500 euros.
- The installation cost for one device is 4 500 euros.
- Each process requires telemetry at a cost of 1 500 euros.

The total investment is 8500 euros × 4 × 8 = 272 000 euros. The estimated time for the payback (PT) time is:

$$PT = \frac{\text{INVESTMENT}}{(\text{TOTAL INCOMES} - \text{TOTAL COST})/\text{YEAR}} = \frac{272\ 000 \text{ euros}}{1\ 987\ 725 \frac{\text{euro}}{\text{year}} - 86\ 474{,}67 \frac{\text{euro}}{\text{year}}}$$

$$PT = 0{,}15 \text{ years} = \pm 2 \text{ months}$$

In a more practical scenario, this PT will be higher because the total cost will exceed the simulation's estimate. But the PT will be still low.

4.4.5.3 Environmental

The DRIP project findings indicated that load-reducing actions were the most effective type of Demand Response (DR) action for decreasing CO_2 emissions. This is because the emissions avoided during the DR event are not later recovered, leading to a net reduction in CO_2 emissions based on the interrupted energy and the average emissions factor of conventional generation. However, these actions often come at an additional cost for the customer due to lost productivity or reduced service levels, making them potentially less attractive from a purely economic standpoint.

Other DR actions like load shifting can reduce CO_2 emissions if the recovery period (when energy consumption is made up) occurs when the power generation's CO_2 emission factor is lower than during the original DR event. CO_2 emission factors vary and are lowest when the share of renewable energy resources is high compared to fossil energy resources. In the simulation tool was the biggest share load-reducing actions so the total CO_2 saving is positive and relatively high for every month.[105]

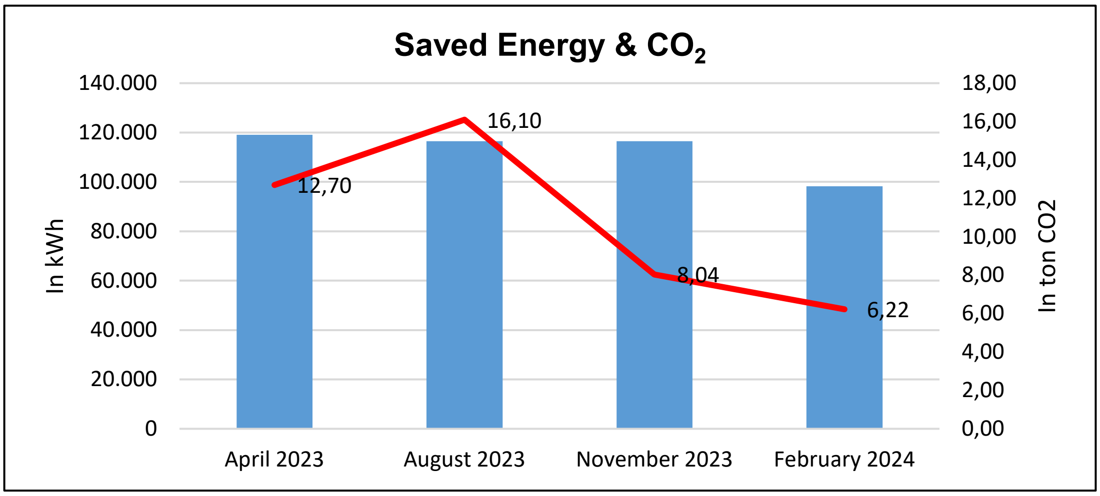

Figure 99: Saved energy (in kWh) and the corresponding saved CO2 (in tons of CO2) for the four scenarios. Source: own elaboration. Source: own elaboration

5 Conclusions

The main objective of this thesis was to design, implement, and validate a methodology for aggregating demand flexibility in the industrial sector, specifically targeting medium-sized food factories in Spain. This objective has been achieved by deploying and assessing the Open Automated Demand Response (OpenADR) technology. The methodology was evaluated from technical, economic, and environmental perspectives with the simulation tool of DRIP using real data from eight food factories in Spain. A detailed technical description of demand response (DR), aggregation and OpenADR implementation was provided, grounded in existing literature and a case study. A general design architecture for aggregating demand flexibility using OpenADR was developed. This architecture served as a blueprint for implementing DR, ensuring a systematic approach.

The simulation tool shows that DR actions were effective in reducing energy consumption and CO_2 emissions, while simultaneously delivering significant economic benefits to consumers. The tool also visualises clearly the initial load curve, the final load curve and payments from the TSO for doing technical evaluation. DR actions with high interruptible power emerge as the most cost-effective option. However, the optimal timing for maximizing these benefits is complex due to various factors. For example, delivery prices have a lot of fluctuations. While load curtailment or shedding may be the most profitable DR action for CO_2 reduction, it incurs additional costs for consumers due to lost productivity. It is important to note that the impact on greenhouse gas emissions will vary depending on each country's specific energy mix and future generation plans. As some data input for the total cost in the simulation wasn't available is the payback time very low calculated.

OpenADR is a promising protocol for demand response actions. It offers several advantages over other protocols, such as its flexibility, scalability, and security. However, there are still some challenges to be addressed, such as the need for more widespread adoption in the EU and the development of OpenADR tools. OpenADR excels in information-based communication, improving its interoperability and connection with a wider range of distributed energy resources. For example, OpenADR focuses especially on the communication between a VEN and a VTN and not between a VEN and a distributed energy resource (DER) controller like a PLC. Some improvements for OpenADR tools are possible. For example, there is no way to import data into the used OpenADR platforms for improved integrability. Developing more intuitive and user-friendly interfaces for OpenADR platforms would make it easier for users to configure and manage demand response events, promoting wider adoption and participation in demand response programs. OpenADR's strength lies in its ability to integrate with existing systems and provide a standardized framework for communication between utilities, aggregators, and consumers. This allows greater flexibility and customisation in demand response implementations.

The slow implementation of smart metering for electricity has been identified as a key barrier to the wider adoption of demand response programs. Smart telemetry provides real-time data on energy consumption. Accelerating the deployment of smart meters would significantly enhance the effectiveness and reach of demand response used with the OpenADR protocol. Some other challenges included the need for better integration with existing industrial systems and overcoming regulatory hurdles. DR will, when widely adopted, reduce the need for excessive generation reserves, which are currently necessary to balance power grids with the increasing integration of renewable energy sources. This flexibility will prove crucial for maintaining efficient power system balancing in the future.

Further analysis is needed to fully understand how the connection to the DER controller works and how different signal types created in OpenADR can be integrated with various DERs. This would involve investigating these communication interfaces used by different DER controllers and developing standardized methods. Also, the required notification time for the different industrial processes can be analysed for optimising the required notification time. Additionally, a comprehensive investigation into the regulatory landscape is crucial to ensure the compliant adoption of OpenADR in diverse energy systems. DR will, when widely adopted, reduce the need for excessive generation reserves, which are currently necessary to balance power grids with the increasing integration of renewable energy sources. This flexibility will prove crucial for maintaining efficient power system balancing in the future.

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APPENDICES

Appendix 1: OpenADR Signal Definitions

OpenADR profile B allows for a more diverse set of signals in the event messages. The eiEventSignal: signalName, eiEventSignal:signalType, and eiEventSignal:itemBase attributes are used to describe the signal. The table lists standard pre-defined signals that may be used. The purpose of the pre-defined signals is to establish a common set of signals and their attributes for the purposes of interoperability. For compliance purposes it is not a requirement that a VTN or VEN support all the signals listed in the table below.

Furthermore specific deployments are free to define their own custom signals beyond what are defined in the table below, but there are no requirements for compliance purposes that any VTN's or VEN's support such signals.

Appendix 2: Specifications of the used OpenADR hardware for the VEN

This section gives a full overview of the used OpenADR hardware for the VEN. Specifications and wiring diagram can be found for the used VEN "GRIDlink VT-IPM2M 113 series".

Appendix 3: Configure VTN Connection Settings

This appendix describes the different settings for configurating the VTN.

Appendix 4: Glossary of Enumerated Values

A complete list of defined values from the OpenADR protocol.

Appendix 5: Overview of the GRIDview user interface

This appendix shows some screenshots from the GRIDview user Interface for clarifying the possibilities.

Appendix 6: Results of the simulation tool developed during the DRIP project

Appendix 1: OpenADR Signal Definitions

Signal Category	Name (signal-Name)	Type (sig-nalType)	units (item-Base)	Allowed Values	Description
Simple levels	SIMPLE	level	None	0,1,2,3	Simple levels
Price of electricity	ELECTRICI-TY_PRICE	price	curren-cy/kWh	any	This is the cost of elec-tricity expressed in abso-lute terms
	ELECTRICI-TY_PRICE	pric-eRelative	curren-cy/kWh	any	This is a delta change to the existing price of elec-tricity
	ELECTRICI-TY_PRICE	priceMulti-plier	None	any	This is a multiplier to the existing cost of electricity
Price of energy	ENERGY_PRICE	price	curren-cy/kWh	any	This is the cost of energy expressed in absolute terms
	ENERGY_PRICE	pric-eRelative	curren-cy/kWh	any	This is a delta change to the existing price of ener-gy
	ENERGY_PRICE	priceMulti-plier	None	any	This is a multiplier to the existing cost of energy
Demand charge	DEMAND_CHARGE	price	currency/kW	any	This is the demand charge expressed in absolute terms
	DEMAND_CHARGE	pric-eRelative	currency/kW	any	This is a delta change to the existing demand charge
	DEMAND_CHARGE	priceMulti-plier	None	any	This is a multiplier to the existing demand charge
Customer bid levels	BID_PRICE	price	currency/XX (2)	any	This is the price that was bid by the resource
	BID_LOAD	setpoint	powerXXX (1)	any	This is the amount of load that was bid by a resource into a program
	BID_ENERGY	setpoint	energyXXX (1)	any	This is the amount of en-ergy from a resource that was bid into a program
Used to dispatch storage resources	CHARGE_STATE	setpoint	energyXXX (1)	any	This is used to either charge or discharge a certain amount of energy from a storage resource until its charge state reaches a certain level.
	CHARGE_STATE	delta	energyXXX (1)	any	This is the delta amount of energy that should be con-tained in a storage re-source from where it cur-rently is.
	CHARGE_STATE	multiplier	None	0.0 < 1.0	This is the percentage of full charge that the storage resource should be at.

These instructions are used to set the load to values that can be expressed in terms of the desired load	LOAD_DISPATCH	setpoint	powerXXX (1)	any	This is used to dispatch loads to a specific amount
	LOAD_DISPATCH	delta	powerXXX (1)	any	This is used to dispatch loads to some offset from an agreed upon baseline. Note that the baseline may be the current power consumption.
	LOAD_DISPATCH	multiplier	None	any	This is used to dispatch loads as some multiple of power against some agreed upon baseline. Note that the baseline may be the current power consumption.
	LOAD_DISPATCH	level	powerXXX	integer value from -10 to +10	This is used to specify the load in terms of discrete levels.
These instructions are used to set the load control to values that are relative to the load controller and its output capacity. This does not require the VTN or the VEN knowing precisely what the load consumption level is, but are expressed in ways that the VTN can know that the signal values will either increase or decrease the load consumption regardless of the specific type of device that is performing the load control. These can be used for some aspects of direct load control by mapping these general instructions to specific load control commands in the VEN without the VTN needing to know precisely what device may be con suming the signal.	LOAD_CONTROL	x-loadControlCapacity	None	0 - 100% (0.0 - 1.0)	This is an instruction for the load controller to operate at a level that is some percentage of its maximum load consumption capacity. This can be mapped to specific load controllers to do things like duty cycling. Note that 1.0 refers to 100% consumption. In the case of simple ON/OFF type devices then 0 = OFF and 1 = ON.
	LOAD_CONTROL	x-loadControlLevel-Offset	None	integer value, Positive or negative	Discrete integer levels that are relative to normal operations where 0 is normal operations. There is no requirement to link the setpoints to specific load consumption values, but the intention is that the higher the setpoint the less load is consumed. Note that these are controller set points that can be mapped at the VEN side to something as simple as thermostat temperature set point offsets.

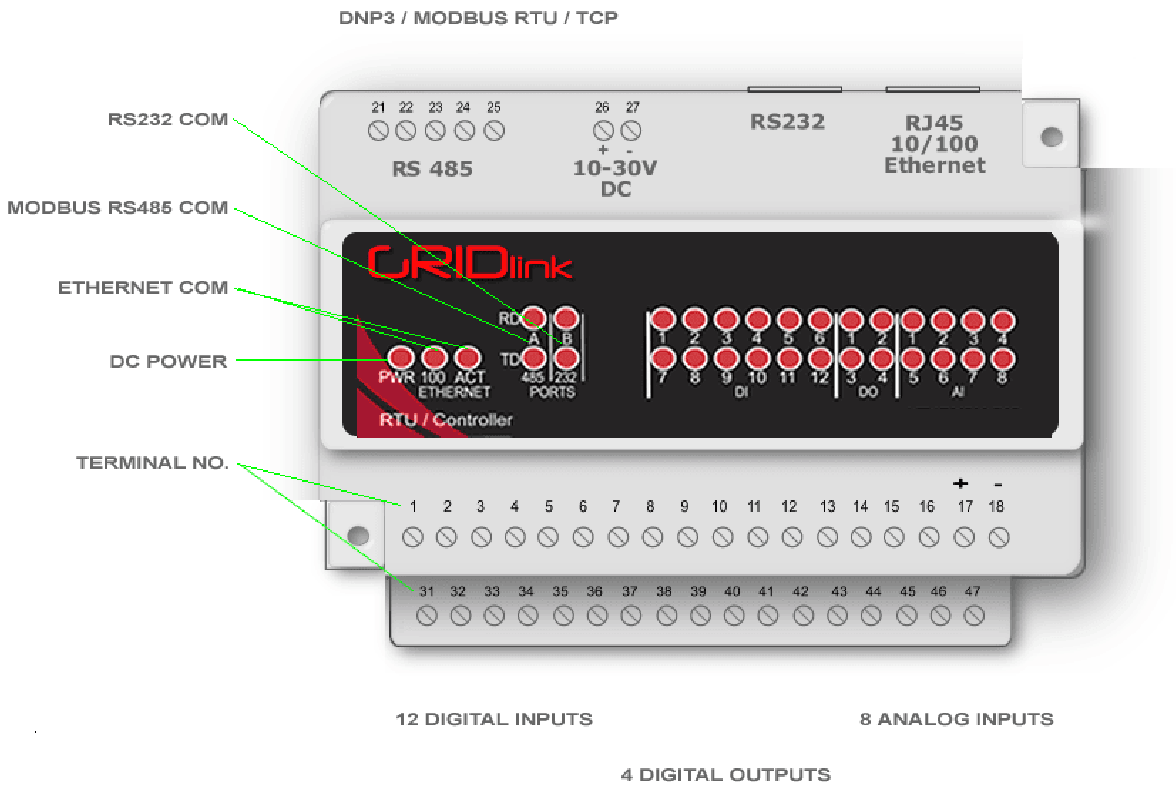
	LOAD_CONTROL	x-loadControlSetpoint	None	any value	Load controller set points. There is no requirement to link the setpoints to specific load consumption values. Note that these are generic controller set points and can be mapped at the VEN side to something as simple as specific thermostat temperature set points.
	LOAD_CONTROL	x-loadControlPercentOffset	None	any percentage, both positive and negative	Percentage change from normal operations. The percentage does not refer to specific load consumptions values, but to load control operation levels. The lower the percentage the less load is consumed.

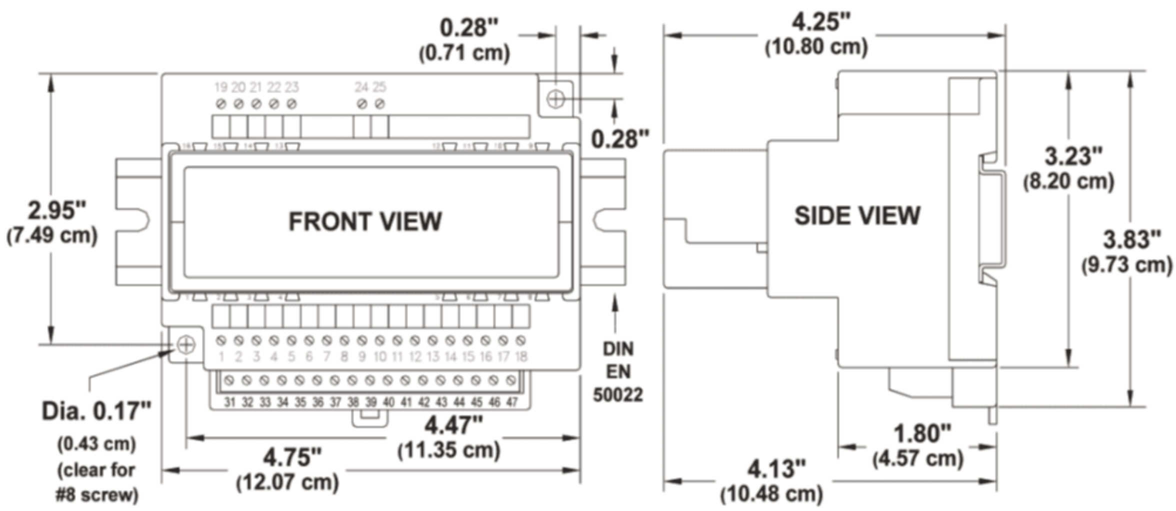
(1) The XXX in the table represents Real, Apparent, and Reactive versions of power or energy

(2) The XX in the table represents the currency unit, such as USD

Appendix 2: Specifications of the used OpenADR hardware

VEN (GRIDlink VT-IPM2M 113 series)





Industrial powerPC (32 bit data bus)

- Operating system embedded Linux
- Dynamic memory (RAM) 32 Mbytes – 32bit, 0 wait states
- Program memory (Flash) 32 Mbytes
- Retained memory (RAM) 512K (battery-backed)
- Local I/O (on-board) 26
- Limit placed on expansion 256 per I/O type
- Data logging (OPTIONAL)
- IEC 61131 programming
- High Level C programming, Linux open source

ETHERNET PORT

- 10/100BaseTx (auto-detecting) RJ45 connection (auto-crossover)
- Protocols TCP/IP, ARP, UDP, ICNP, DHCP, Modbus/TCP, SIXNET, and more

SERIAL PORT

- RS485 port A screws (485+, 485-, GND) 2-wire half-duplex
- RS232 Port B RJ45 (TD, RD, CTS, RTS, CD, DTR,DSR, GND)
- Protocols (master & slave) Modbus RTU/ASCII, Optional DNP3 slave
- Flow control hardware, software, RTS-party (for radios and RS485)

ANALOG

- Input channels (4-20 mA)
- (optional) output channels (4-20mA)
- A/D resolution 16 bits (0.003%)
- Full scale accuracy +/-0.1% (@20°C)
- Span and offset temp. coef. +/-50 ppm per °C
- Input impedance 100 Ohm
- Current protection Self-resetting fuses
- DMRR (differential mode rejection) 66 dB at 50/60 Hz

ENVIRONMENTAL

- Input power 10-30 VDC
- Input current 100 mA @ 24 VDC (typical)
- Operating Temperature -40 to 70°C (-40 to 85°C storage)
- Shock: IEC60068-2-27
- Vibration: IEC60068-2-6
- Humidity 5% to 95% RH (non-condensing)

DISCRETE INPUTS

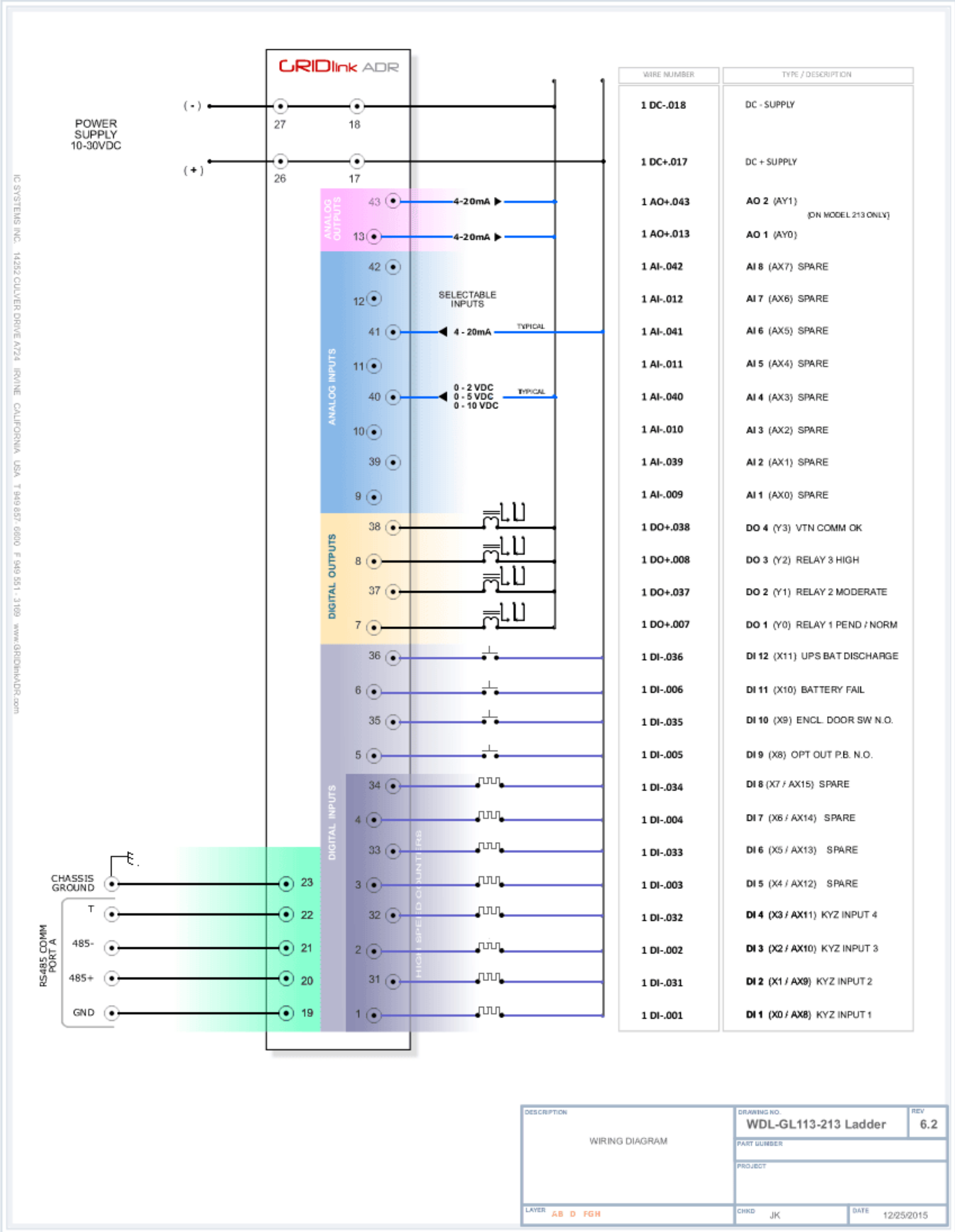
- 12 channels (sinking or sourcing) for manual input and force load shed
- Guaranteed ON voltage 9 VDC
- Maximum voltage 30 VDC
- Guaranteed OFF voltage & current 5.0 VDC & 1.5 mA DC
- Input resistance 10K Ohms
- Input current @ 24 VDC 3 mA
- Filtered ON/OFF delay 25 mS (20 Hz max. counting)
- Fast ON/OFF delay 4 mS (100 Hz max. counting)
- Count rate (channels 1 – 8) High Speed Counter (10 KHz on channel 1)

DISCRETE OUTPUTS

- 4 channels (10-30 VDC)
  - 1 for Pending Notice
  - 2 for Simple Event Load Shed (Moderate, High)
  - 1 for Off Line Indication
- Maximum output per channel 1 Amp
- Maximum output per module 4 Amps
- Max. OFF state leakage 0.05 mA
- Minimum load 1 mA
- Inrush current 5 Amps (100 mS surge)
- Typical ON resistance 0.3 Ohms
- Typical ON voltage (@1A) 0.3 VDC

CERTIFICATIONS

- Flammability UL 94V-0 materials
- Electrical safety UL 508, CSA C22.2/14; EN610101; (IEC1010); CE
- EMI emissions FCC part 15, ICES-003, Class A; EN55022; EN61326-1; CE
- EMC immunity EN61326-1 (EN61000-4-2,3,4,6); CE
- Surge withstand IEEE-472 (ANSI C37.90)
- Vibration IEC68-2-6
- Hazardous locations (Class 1, Div 2, Groups A,B,C,D) UL 1604, CSA C22.2/213, Cenelec EN50021 Zone 2
- Tested to Marine/offshore standards


GRIDlink ADR
POWER SUPPLY 10-30VDC
(-)
(+)
ANALOG OUTPUTS
4-20mA
ANALOG INPUTS
SELECTABLE INPUTS
4 - 20mA
TYPICAL
0 - 2 VDC
0 - 5 VDC
0 - 10 VDC
DIGITAL OUTPUTS
DIGITAL INPUTS
HIGH SPEED COUNTERS
CHASSIS GROUND
RS485 COMM PORT A
T
485-
485+
GND
WIRE NUMBER
TYPE / DESCRIPTION
1 DC-.018 DC - SUPPLY
1 DC+.017 DC + SUPPLY
1 AO+.043 AO 2 (AY1) (ON MODEL 213 ONLY)
1 AO+.013 AO 1 (AY0)
1 AI-.042 AI 8 (AX7) SPARE
1 AI-.012 AI 7 (AX6) SPARE
1 AI-.041 AI 6 (AX5) SPARE
1 AI-.011 AI 5 (AX4) SPARE
1 AI-.040 AI 4 (AX3) SPARE
1 AI-.010 AI 3 (AX2) SPARE
1 AI-.039 AI 2 (AX1) SPARE
1 AI-.009 AI 1 (AX0) SPARE
1 DO+.038 DO 4 (Y3) VTN COMM OK
1 DO+.008 DO 3 (Y2) RELAY 3 HIGH
1 DO+.037 DO 2 (Y1) RELAY 2 MODERATE
1 DO+.007 DO 1 (Y0) RELAY 1 PEND / NORM
1 DI-.036 DI 12 (X11) UPS BAT DISCHARGE
1 DI-.006 DI 11 (X10) BATTERY FAIL
1 DI-.035 DI 10 (X9) ENCL. DOOR SW N.O.
1 DI-.005 DI 9 (X8) OPT OUT P.B. N.O.
1 DI-.034 DI 8 (X7 / AX15) SPARE
1 DI-.004 DI 7 (X6 / AX14) SPARE
1 DI-.033 DI 6 (X5 / AX13) SPARE
1 DI-.003 DI 5 (X4 / AX12) SPARE
1 DI-.032 DI 4 (X3 / AX11) KYZ INPUT 4
1 DI-.002 DI 3 (X2 / AX10) KYZ INPUT 3
1 DI-.031 DI 2 (X1 / AX9) KYZ INPUT 2
1 DI-.001 DI 1 (X0 / AX8) KYZ INPUT 1
DESCRIPTION
WIRING DIAGRAM
DRAWING NO.
WDL-GL113-213 Ladder
REV
6.2
PART NUMBER
PROJECT
LAYER
CHKD
JK
DATE
12/25/2015

Appendix 3: Configure VTN Connection Settings

== CONNECTION ==

service_hostname
Fully qualified domain name to connect with the VTN.
Required.

service_prefix
Any prefix to insert when forming the URL.

service_port
TCP port to use when communicating with the VTN.
Default is 80 when SSL is disabled, 443 with SSL enabled.

server_post_max
Maximum amount of data the server allows us to post, in bytes.
Default is 131072.

ven_id
Virtual *end* node ("client") ID (This provides a place to record the VEN ID for future reference which is provided by the VTN)

vtn_id
Virtual *top* node ("server") ID

market_context1 (or market_context)
First market context to match.
Default is blank (match any).

market_context2
Second market context to match.
Default is blank (match any).

device_class
One item from oadrDeviceClass (see OADR 2.0b CR111 for a list).

== SECURITY ==

service_use_ssl
Set to 1 to enable SSL when communicating with the server.
Set to 0 to disable (enabled by default).

ssl_verify
Set to 1 to enable SSL certificate verification when communicating with the server. Set to 0 to disable (enabled by default).
When SSL verification fails, temporarily disabling ssl_verify can re-establish communication. The long-term fix is to update the SSL certificate used by the GRIDlink to the one used by the VTN server's certificate authority (CA).

auth_user
Username for HTTP authentication.

auth_password
Password for HTTP authentication.

== OPTIONS ==

log_level
Set the logging verbosity. Possible values are:
DEBUG5 (Maximum)
DEBUG4
DEBUG3
DEBUG2
DEBUG1
INFO
NOTICE (Normal – Default)
WARNING
ERROR
LOG
FATAL
PANIC (Minimum)

log_silence
Causes the program to omit messages matching any part of this
string in the FILE and TOPIC parameters. The log messages from
any number of source files or functions may be silenced using
this parameter by including them in a quoted string

eievent_enabled
Enable eiEvent service. Defaults to enabled (1).

eiopt_enabled
Enable eiOpt service. Defaults to enabled (1).

eiregisterparty_enabled
Enable eiRegisterParty service. Defaults to enabled (1).

eiregisterparty_use_cached
Use previous registration details when starting up.
Defaults to enabled (1).

eireport_enabled
Enable eiReport service. Defaults to enabled (1).

kyz_meter
Enable power meter handling logic. Default is disabled (0).

kyz_counter_register
Specify the Analog Input register that holds the raw power meter count. Default is 32000, which is probably not what
you want. The first counter register for a DI in Sixnet is AI:8 by default. The
accumulated count is stored in LI:0

dras_push
Set to 1 to enable "push" logic which monitors a file location for event info. Default is disabled (0).
This is a planned enhancement but not currently supported.

load_calc
Set to 1 to enable load calculation logic using the kyz counter.
Default is disabled (0).

shed_level_calc
Set to 1 to enable shed level calculation logic.
Default is disabled (0).

load_calc_period
Number of minutes between load_calcs. Default is 15.

== OPT-OUT/OPT-IN ==

Configurable through I/O registers or INI parameters, the opt-out service implementation on GRIDlink assumes opt-in unless otherwise specified.

When I/O register values are specified, they override INI parameter values.
A duration of 0 specifies an open-ended opt-out period. Both parameters must be present in the INI file to be valid. Opt start times in the distant past may be ignored.

opt_id
(optional) fixed optID for testing EiOpt. If blank a unique
ID is created using the current timestamp and the venId.

opt_type
0 to opt-out, 1 to opt-in.

opt1_start
Time (unix epoch, seconds since 1970-01-01 00:00 UTC) to start first opt-out period.

opt1_duration
Duration in seconds for first opt-out period.

opt2_start
Time (unix epoch, seconds since 1970-01-01 00:00 UTC) to start second opt-out period.

opt2_duration
Duration in seconds for second opt-out period.

== ADVANCED ==

curl_trace_get
File to store results of HTTP requests.

dras_poll_delay
Time in seconds between polls for events. This value is overridden by any value from the VTN.

dras_poll_jitter
Randomization time for server polls.

max_disconnect_delay
Time the GRIDlink will allow communication to the VTN to be offline before deleting current event information and returning to normal mode (seconds).

max_execdisconnect_delay
Time during an active event the GridLink will allow communication to the VTN to be offline before deleting current event information and returning to normal mode (seconds).

report_poll_delay
Time in milliseconds between calls to the report logic. This should be less than the minimum report item sample time.

report_send_delay
(proposed) Time in seconds between attempts to post report data on the server. Actual post interval is determined by the server oadrCreatedReport and the defined server_post_max. See CR312 for more details.

report_type
Integer specifying the report type 0=usage, 1=delta. Other report types may be defined in the future per the OADR specification.

revision
Optional long integer indicating the configuration version.
This is output to LO:1 for monitoring by other software.

Appendix 4: Glossary of Enumerated Values

SOURCE: OpenADR 2.0 Demand Response Program Implementation Guide

G.1 eventStatus

active The event has been initiated and is currently active.

canceled The event has been canceled.

completed The event has completed.

far Event pending in the far future. The exact definition of how far in the future this refers is dependent upon the market context, but typically means the next day.

near Event pending in the near future. The exact definition of how near in the future the pending event is active is dependent on the market context. Starts concurrent with effective start of the event x-eiRampUp time. If x-eiRampUp is not defined for the event, this status will not be used for the event.

none No event pending

G.2 itemUnits

Currency

USD - United States Dollars

To many to list here …

powerReal

J/s - Joule-second

W - Watts

temperature

celsius

fahrenheit

G.3 oadrDataQuality

No New Value - Previous Value Used -

No Quality - No Value -

Quality Bad - Comm Failure -

Quality Bad - Configuration Error -

Quality Bad - Device Failure -

Quality Bad - Last Known Value -

Quality Bad - Non Specific -

Quality Bad - Not Connected -

Q**uality Bad - Out of Service** -

Quality Bad - Sensor Failure -

Quality Good - Local Override -

Quality Good - Non Specific -

Quality Limit - Field/Constant -

Quality Limit - Field/High -

Quality Limit - Field/Low -

Quality Limit - Field/Not -

Quality Uncertain - EU Units Exceeded -

Quality Uncertain - Last Usable Value -

Quality Uncertain - Non Specific -

Quality Uncertain - Sensor Not Accurate -

Quality Uncertain - Sub Normal -

G.4 oadrResponseRequired

always - Always send a response for every event received.

never - Never respond.

G.5 optReason

Enumerated reasons for opting.

economic -

emergency -

mustRun -

notParticipating -

outageRunStatus -

overrideStatus -

participating -

x-schedule –

G.6 oadrTransportName

simpleHttp -

xmpp –

G.7 OptType

optIn - An indication that the VEN will participate in an event, or in the case of the EiOpt service a type of schedule indicating that resource will be available

optOut - An indication that the VEN will not participate in an event, or in the case of the EiOpt service a type of schedule indicating that resource will be not available

G.8 readingType

Allocated - Meter covers several [resources] and usage is inferred through some sort of pro data computation.

Contract - Indicates reading is pro forma, i.e., is reported at agreed upon rates

Derived - Usage is inferred through knowledge of run-time, normal operation, etc.

Direct Read - Reading is read from a device that increases monotonically, and usage must be computed from pairs of start and stop readings.

Estimated - Used when a reading is absent in a series in which most readings are present.

Hybrid - If aggregated, refers to different reading types in the aggregate number.

Mean - Reading is the mean value over the period indicated in Granularity

Net - Meter or [resource] prepares its own calculation of total use over time.

Peak - Reading is Peak (highest) value over the period indicated in granularity. For some measurements, it may make more sense as the lowest value. May not be consistent with aggregate readings. Only valid for flow-rate Item Bases, i.e., Power not Energy.

Projected – Indicates reading is in the future, and has not yet been measured.

Summed - Several meters together provide the reading for this [resource]. This is specifically a different than aggregated, which refers to multiple [resources] in the same payload. See also Hybrid.

x-notApplicable - Not Applicable

x-RMS - Root Mean Square

G.9 reportName

HISTORY_GREENBUTTON - A report containing greenbutton data in an atom feed schema structure

HISTORY_USAGE - A report containing histrorical energy usage data

METADATA_HISTORY_GREENBUTTON - A metadata report defining the reporting capabilities for HISTORY_GREENBUTTON reports

METADATA_HISTORY_USAGE - A metadata report defining the reporting capabilities for HISTORY_USAGE reports

METADATA_TELEMETRY_STATUS - A metadata report defining the reporting capabilities for TELEMETRY_STATUS reports

METADATA_TELEMETRY_USAGE - A metadata report defining the reporting capabilities for TELEMETRY_USAGE reports

TELEMETRY_STATUS - A report containing real time resource status information such as online state

TELEMETRY_USAGE A report containing real time energy usage information

G.10 reportType

An enumerated value that gives the type of report being provided.

availableEnergyStorage Capacity available for further energy storage, perhaps to get to Target Energy Storage

avgDemand Average usage over the duration indicated by the Granularity. See demand for more information.

avgUsage - Average usage over the duration indicated by the Granularity. See usage for more information.

baseline - Can be demand or usage, as indicated by ItemBase. Indicates what [measurement] would be if not for the event or regulation. Report is of the format Baseline.

deltaDemand - Change in demand as compared to the baseline. See demand for more information

deltaSetPoint - Changes in setpoint from previous schedule.

deltaUsage - Change in usage as compared to the baseline. See usage for more information

demand - Report indicates an amount of units (denominated in ItemBase or in the EMIX Product). Payload type is Quantity. A typical ItemBase is Real Power.

deviation - Difference between some instruction and actual state.

downRegulationCapacityAvailable - Down Regulation capacity available for dispatch, expressed in EMIX Real Power. Payload is always expressed as positive Quantity.

level - Simple level from market at each Interval.

operatingState - Generalized state of a resource such as on/off, occupancy of building, etc. No ItemBase is relevant. Requires an Application Specific Payload Extension.

percentDemand - Percentage of demand

percentUsage - Percentage of usage

powerFactor - Power factor for the resource

price - Price per ItemBase at each Interval

reading - Report indicates a reading, as from a meter. Readings are moments in time-changes over time can be computed from the difference between successive readings. Payload type is float

regulationSetpoint - Regulation setpoint as instructed as part of regulation services

setPoint - Report indicates the amount (denominated in ItemBase or in the EMIX Product) currently set. May be a onfirmation/return of the setpoint control value sent from the VTN. Payload type is Quantity. A typical ItemBase is Real Power.

storedEnergy - Stored Energy is expressed as Real Energy and Payload is expressed as a Quantity.

targetEnergyStorage - Target Energy is expressed as Real Energy and Payload is expressed as a Quantity.

upRegulationCapacityAvailable - Up Regulation capacity available for dispatch, expressed in EMIX Real Power. Payload is always expressed as positive Quantity.

usage - Report indicates an amount of units (denominated in ItemBase or in the EMIX Product) over a period. Payload type is Quantity. A typical ItemBase is RealEnergy

•**x-resourceStatus** - Percentage of demand

G.11 scaleCode

p - Pico 10^-12

n - Nano 10^-9

micro - Micro 10^-6

m - Milli 10^-3

c - Centi 10^-2

d - Deci 10^-1

k - Kilo 10^3

M - Mega 10^6

G - Giga 10^9

T - Tera 10^12

none - Native Scale

G.12 signalName

BID_ENERGY - This is the amount of energy from a resource that was bid into a program

BID_LOAD - This is the amount of load that was bid by a resource into a program

BID_PRICE - This is the price that was bid by the resource

CHARGE_STATE - State of energy storage resource

DEMAND_CHARGE - This is the demand charge

ELECTRICITY_PRICE - This is the cost of electricity

ENERGY_PRICE - This is the cost of energy

LOAD_CONTROL - Set load output to relative values

LOAD_DISPATCH – This is used to dispatch load

simple - depreciated - for backwards compatibility with A profile

SIMPLE - Simple levels (OpenADR 2.0a compliant)

G.13 signalType

An enumerated value describing the type of signal such as level or price

delta - Signal indicates the amount to change from what one would have used without the signal.

level - Signal indicates a program level.

multiplier - Signal indicates a multiplier applied to the current rate of delivery or usage from what one would have used without the signal.

price - Signal indicates the price.

priceMultiplier - Signal indicates the price multiplier. Extended price is the computed price value multiplied by the number of units.

priceRelative - Signal indicates the relative price.

setpoint - Signal indicates a target amount of units.

x-loadControlCapacity - This is an instruction for the load controller to operate at a level that is some percentage of its maximum load consumption capacity. This can be mapped to specific load controllers to do things like duty cycling. Note that 1.0 refers to 100% consumption. In the case of simple ON/OFF type devices then 0 = OFF and 1 = ON.

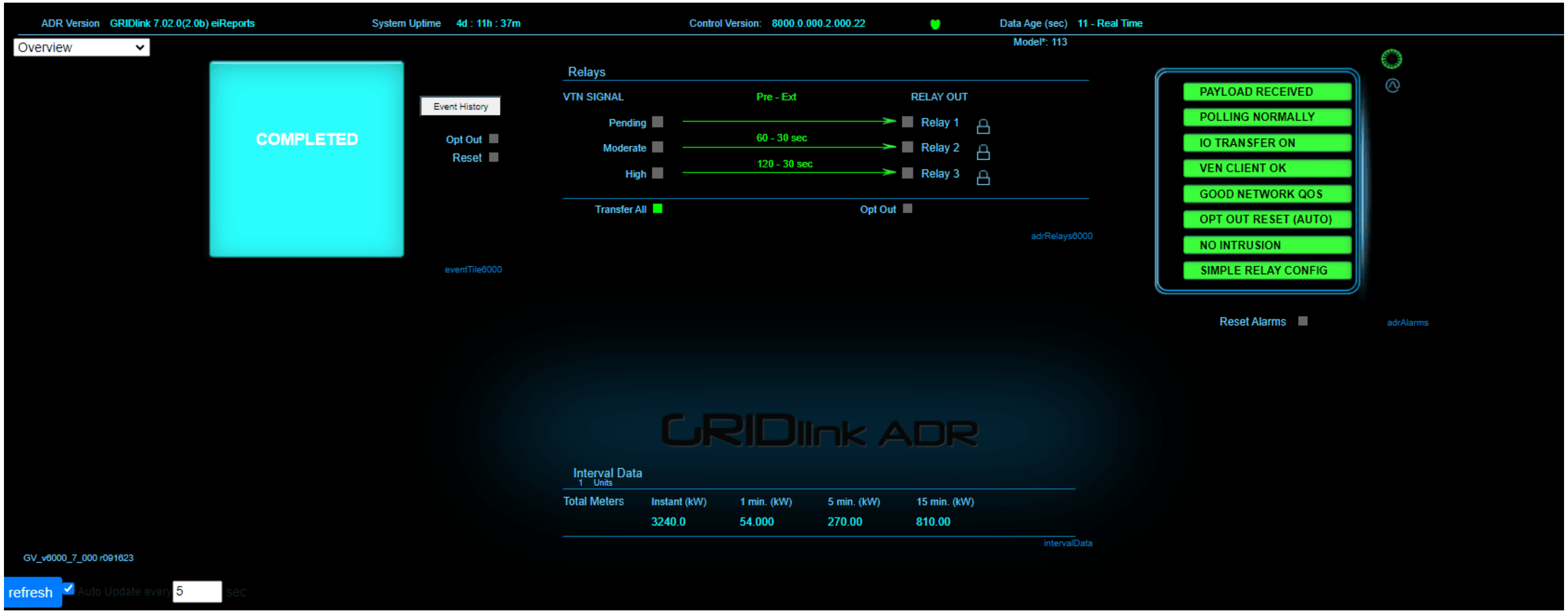
x-loadControlLevelOffset - Discrete integer levels that are relative to normal operations where 0 is normal operations.

x-loadControlPercentOffset - Percentage change from normal load control operations.

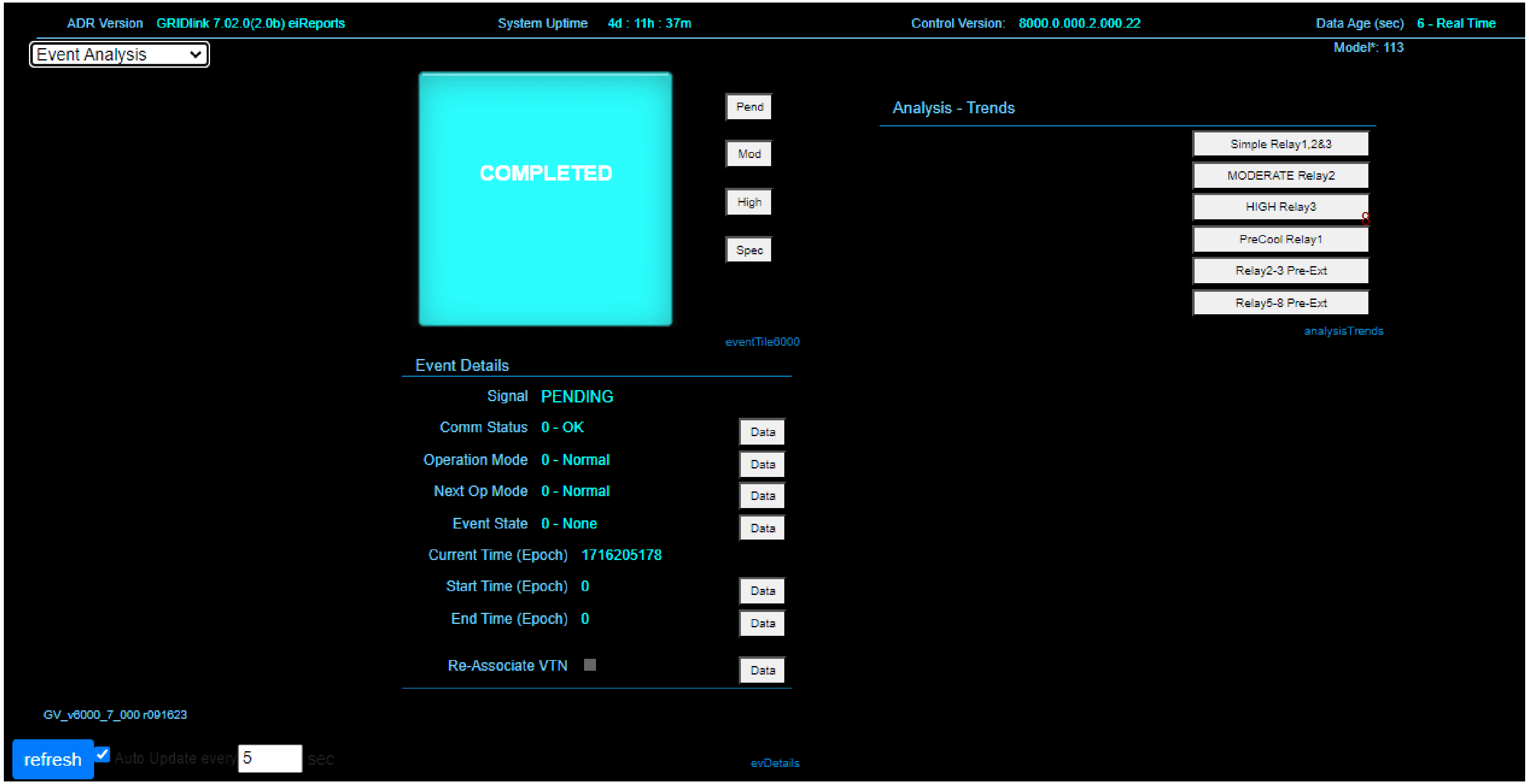
x-loadControlSetpoint - Load controller set points.

Appendix 5: Overview of the GRIDview user interface

OVERVIEW



EVENT ANALYSIS



TEST SIGNAL


ADR Version GRIDlink 7.02.0(2.0b) eiReports
System Uptime 4d : 11h : 38m
Control Version: 8000.0.000.2.000.22
Data Age (sec) 2 - Real Time
Model*: 113
Test Signal
Test Signal
Set Pending Minutes (2160 max) 1 Send Cancel
Set Duration Minutes (720 max) 6 Send Cancel
Signal Name (SIMPLE) 101 Send Cancel
Signal Type (level) 202 Send Cancel
Signal Value 0 Send Cancel
testSignal
Relays
VTN SIGNAL
Pre - Ext
RELAY OUT
Pending
Moderate
High
60 - 30 sec
120 - 30 sec
Relay 1
Relay 2
Relay 3
Data
Transfer All
Opt Out
adrRelays6000
2.0b Signals
Signal Name
101 - SIMPLE
102 - ELECTRICITY_PRICE
103 - ENERGY_PRICE
104 - DEMAND_CHARGE
105 - BID_PRICE
106 - BID_LOAD
107 - BID_ENERGY
108 - CHARGE_STATE
109 - LOAD_DISPATCH
110 - LOAD_CONTROL
Signal Type
200 - none
201 - delta
202 - level
203 - multiplier
204 - price
205 - priceMultiplier
206 - priceRelative
207 - product
208 - setpoint
Signal Value
1 - Simple Moderate
2 - Simple High
3 - Special (refer 2.0b Spec)
or Refer to Control Signal Map
signals2b
GV_v6000_7_000 r091623
refresh
Auto Update every 5 sec

ALARMS – QUALITY OF SERVICE (QOS)

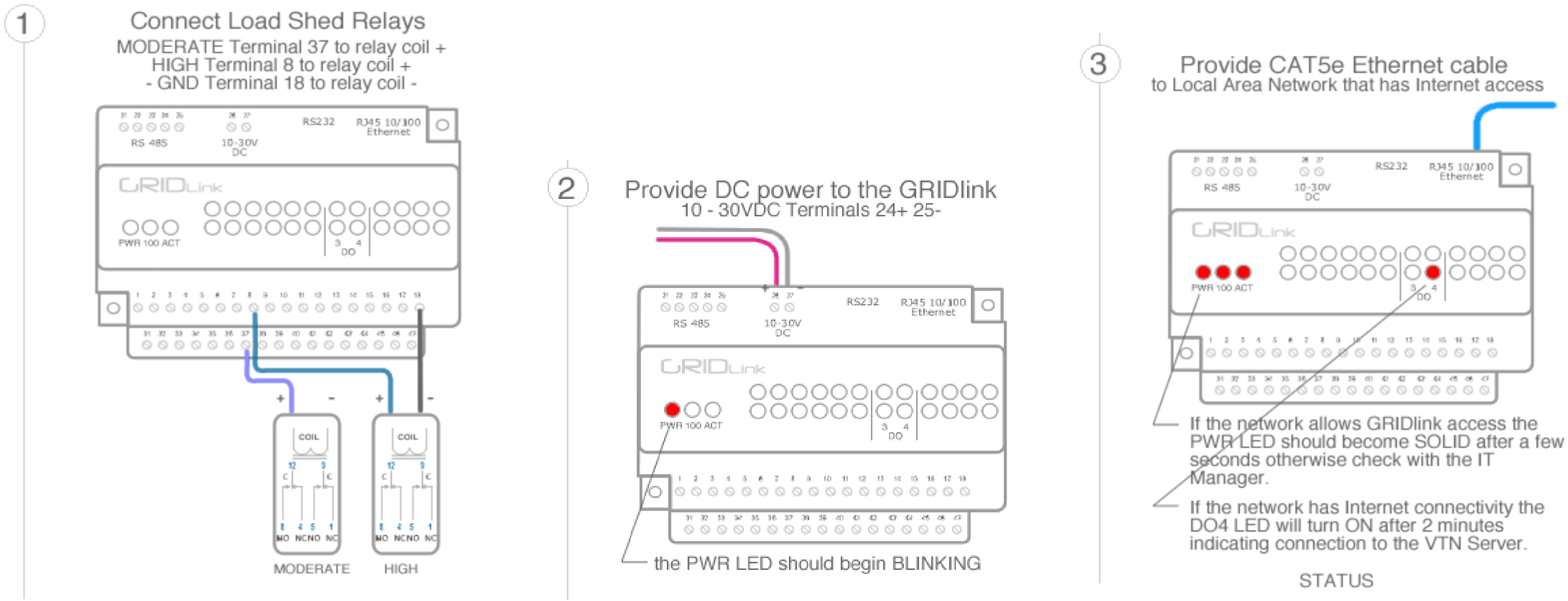
GENERAL ALARM CODE	DEFINED IN LINE OF CODE
201	Dynamic ADR not enabled
202	Special Signal Value cannot be 0
DYNAMIC ADR	kW, Frequency, kVAR, Volts defined in DynAlarm (* Alarms Dynamic ADR Prog *)
101	Dynamic ADR not enabled
102	No Dynamic ADR program selected
103	Source Meter not Defined
104	Source Meter Type not Defined
105	Source Meter not Enabled
106	Source is not a Modbus Meter
107	Source Pv not Defined
108	Base & Upper Limit cannot be 0
109	PID is Disabled

RELAY CONFIG

DEVICE CONFIG

METER DATA / CONFIG

INSTALLATION



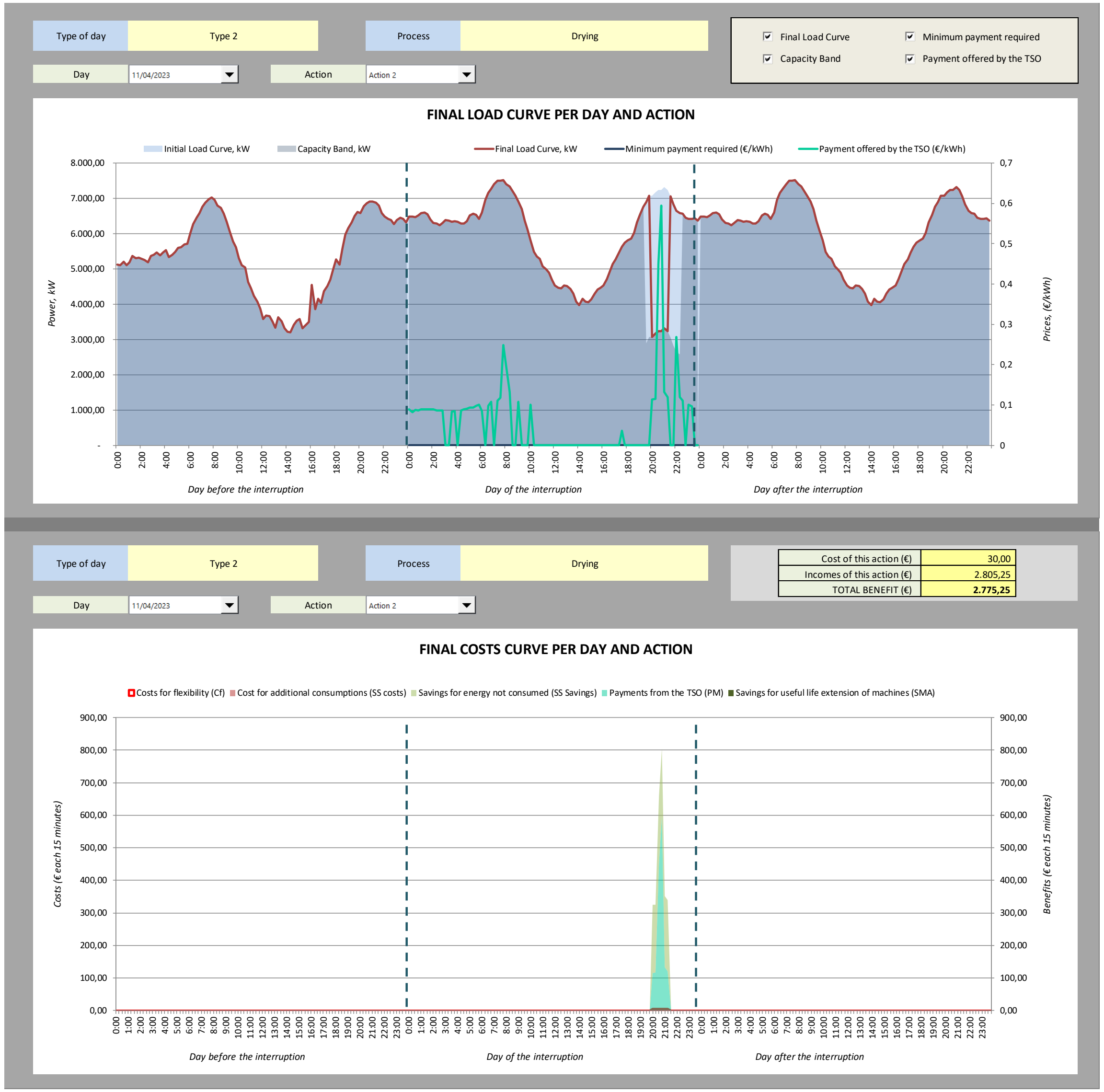
Appendix 6: Parameters and results of the simulation tool developed during the DRIP project

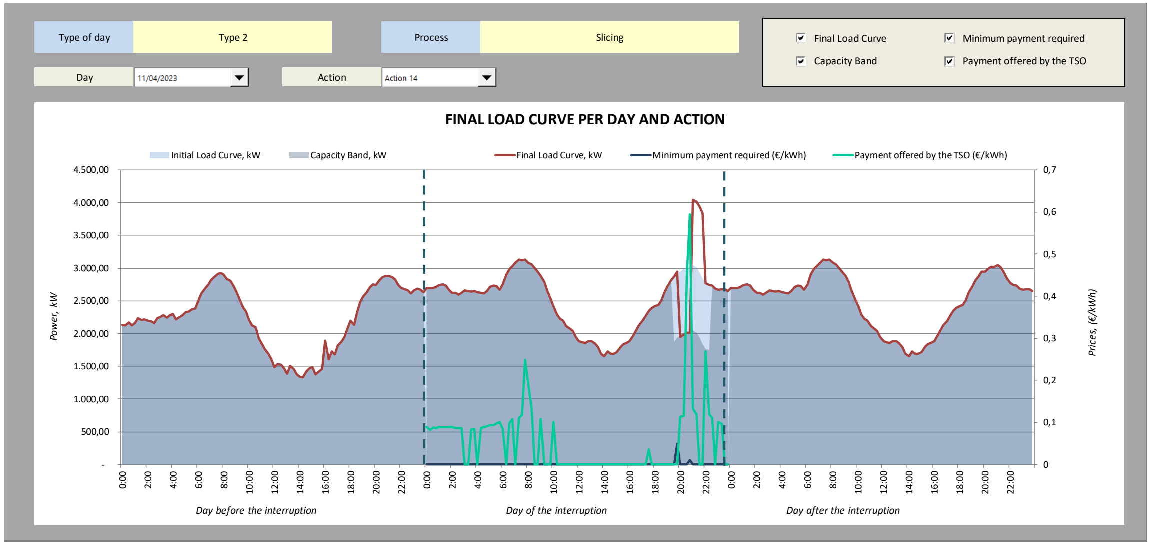
Chosen technical parameters of DR actions in the meat factories

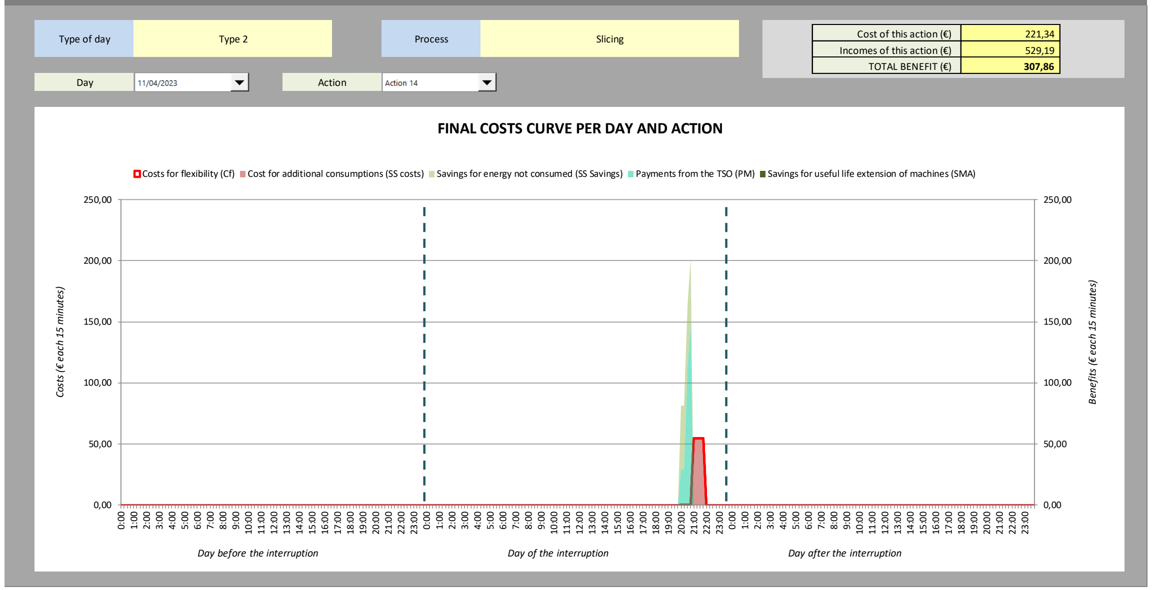
Parameter (summer/winter)	Drying	Maturing	Freezing store 81	Slicing
ΔPR_1: Interruptible power (kW)	283	102	70/45	82/36
ΔPR_2: Additional power BEFORE interruption (kW)	0	0	0	0
ΔPR_3: Additional power AFTER interruption (kW)	0	15	30/27	82/72
T_D: Duration of the action (hours)	2	3	3	1/2
T_{av}: Operation times (hours)	24 hours a day	24 hours a day	24 hours a day	from Monday-6h to Saturday-6h
T_{PR}: Duration of the preparation (hours)	0	0	0	0
T_{RC}: Recovery period (hours)	0	21	7/5	1
T_{IA}: Advance notification time (hours)	15 minutes	15 minutes	15 minutes	15 minutes
T_{MIN}: Minimum time between interruptions (hours)	22	21	21	22
Is it possible to postpone the Recovery Period?	No	No	No	No
Linked DR actions	No	No	No	No

RESULTS FOR THE WHOLE MONTH - April 2023 (Tertiary reserve)

	Initial consumption *kWh*	Final consumption *kWh*	Energy balance *kWh*	CO_2 balance *tonCO₂*	Economical energy balance (S_S) *euro*	Minimum payment required by customers (P_M^{min}) *euro*	Payment offered by the TSO (P_M) *euro*	Margin of decission (P_M-P_M^{min}) *euro*	TOTAL COSTS ($C_f + S_s^-$) *euro*	TOTAL INCOMES ($S_{MA} + S_S^+ + P_M$) *euro*	NET BENEFIT FOR THE CUSTOMER *euro*
31/03/2023	375.958,9	375.958,9	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/05/2023	332.948,8	332.948,8	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/04/2023	254.121,5	253.031,5	1.090,0	0,09	73,56	4,07	92,00	87,93	48,54	210,42	161,88
2/04/2023	204.223,5	193.933,5	10.290,0	0,75	641,80	3,80	1.049,21	1.045,42	120,08	1.781,77	1.661,69
3/04/2023	332.948,8	331.158,8	1.790,0	0,17	105,34	24,60	450,27	425,67	380,16	924,71	544,55
4/04/2023	375.958,9	373.718,9	2.240,0	0,12	41,03	52,54	454,66	402,12	217,58	705,89	488,31
5/04/2023	375.958,9	375.958,9	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
6/04/2023	375.958,9	374.838,9	1.120,0	0,07	222,19	0,17	190,84	190,68	130,23	539,58	409,34
7/04/2023	375.958,9	373.718,9	2.240,0	0,22	321,61	22,53	343,31	320,78	285,99	943,54	657,55
8/04/2023	254.121,5	245.401,5	8.720,0	1,53	1.517,74	7,12	1.308,88	1.301,77	373,85	3.171,16	2.797,31
9/04/2023	204.223,5	193.933,5	10.290,0	1,21	1.544,11	3,33	1.217,60	1.214,28	211,02	2.943,42	2.732,40
10/04/2023	332.948,8	325.558,8	7.390,0	1,08	876,11	2,15	1.196,74	1.194,58	490,63	2.534,16	2.043,53
11/04/2023	375.958,9	368.271,4	7.687,5	0,60	1.650,79	5,11	2.585,90	2.580,79	490,76	4.705,42	4.214,66
12/04/2023	375.958,9	365.652,7	10.306,3	0,67	764,01	21,96	1.169,43	1.147,48	330,60	2.234,68	1.904,09
13/04/2023	375.958,9	375.912,7	46,3	0,01	97,41	14,13	320,82	306,69	470,18	881,04	410,86
14/04/2023	375.958,9	374.838,9	1.120,0	0,04	40,69	0,17	37,23	37,07	56,12	130,35	74,23
15/04/2023	254.121,5	253.031,5	1.090,0	0,07	58,27	0,17	49,50	49,34	29,98	134,07	104,09
16/04/2023	204.223,5	196.718,5	7.505,0	0,63	1.099,96	17,45	878,16	860,70	184,46	2.140,54	1.956,08
17/04/2023	332.948,8	331.673,8	1.275,0	0,12	108,47	13,47	325,62	312,15	273,40	700,11	426,72
18/04/2023	375.958,9	373.718,9	2.240,0	0,15	392,21	11,12	371,97	360,84	274,78	1.031,58	756,81
19/04/2023	375.958,9	374.838,9	1.120,0	0,11	201,47	8,68	211,12	202,44	137,96	546,85	408,90
20/04/2023	375.958,9	373.718,9	2.240,0	0,19	392,62	15,49	388,76	373,27	291,27	1.065,28	774,00
21/04/2023	375.958,9	373.718,9	2.240,0	0,19	273,78	24,97	378,35	353,38	271,27	916,02	644,75
22/04/2023	254.121,5	247.581,5	6.540,0	0,77	975,92	0,50	983,41	982,91	287,95	2.225,25	1.937,29
23/04/2023	204.223,5	202.043,5	2.180,0	0,17	208,06	12,07	297,73	285,65	137,53	635,94	498,41
24/04/2023	332.948,8	323.088,8	9.860,0	1,33	1.868,84	16,95	1.708,58	1.691,63	728,39	4.276,34	3.547,95
25/04/2023	375.958,9	375.258,9	700,0	0,03	39,94	33,38	140,81	107,42	196,61	373,67	177,06
26/04/2023	375.958,9	373.718,9	2.240,0	0,26	403,74	8,64	404,75	396,11	273,90	1.075,02	801,12
27/04/2023	375.958,9	373.718,9	2.240,0	0,31	391,00	8,12	391,37	383,25	263,34	1.038,34	775,00
28/04/2023	375.958,9	368.518,9	7.440,0	0,98	1.442,14	5,85	1.182,89	1.177,04	511,04	3.114,04	2.602,99
29/04/2023	254.121,5	249.391,5	4.730,0	0,71	634,79	3,29	708,84	705,55	425,46	1.750,70	1.325,24
30/04/2023	204.223,5	203.133,5	1.090,0	0,12	148,09	0,17	142,84	142,67	65,42	352,66	287,24
-	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL MONTH	**10.347.771,0**	**10.228.710,9**	**119.060,0**	**12,70**	**16.535,67**	**341,99**	**18.981,60**	**18.639,61**	**7.958,48**	**43.082,53**	**35.124,05**

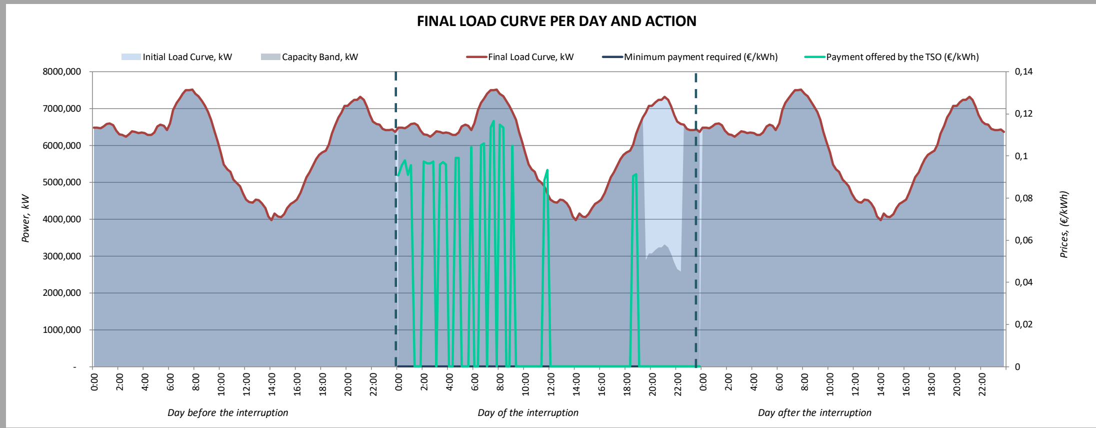

Type of day
Type 2
Process
Drying
Day
11/04/2023
Action
Action 2
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€) 30,00
Incomes of this action (€) 2.805,25
TOTAL BENEFIT (€) 2.775,25
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)


Type of day
Type 2
Process
Slicing
Day
11/04/2023
Action
Action 14
Final Load Curve
Minimum payment required
Capacity Band
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption


Type of day
Type 2
Process
Slicing
Day
11/04/2023
Action
Action 14
Cost of this action (€) 221,34
Incomes of this action (€) 529,19
TOTAL BENEFIT (€) 307,86
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)
Day before the interruption
Day of the interruption
Day after the interruption

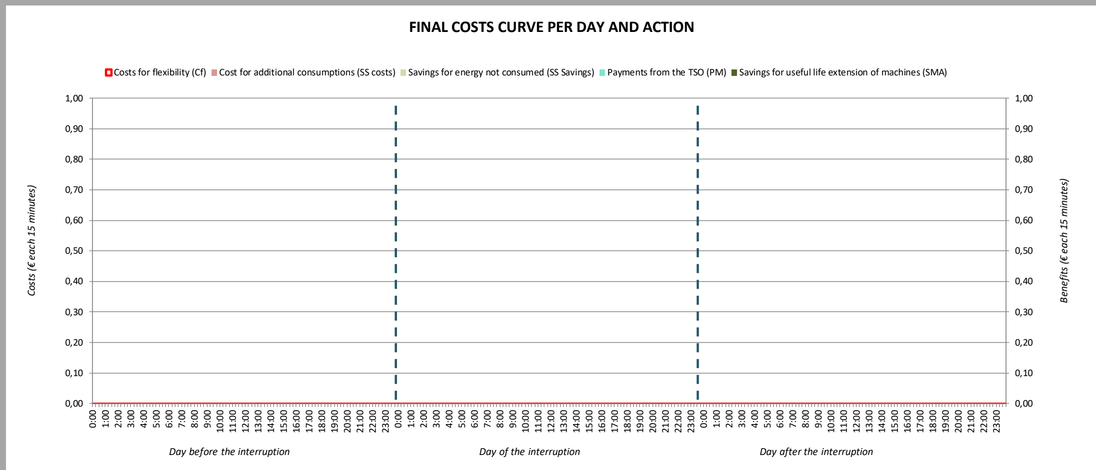
Type of day	Type 2	Process	Drying
Day	5/04/2023	Action	Action 2

☑ Final Load Curve ☑ Minimum payment required
☑ Capacity Band ☑ Payment offered by the TSO



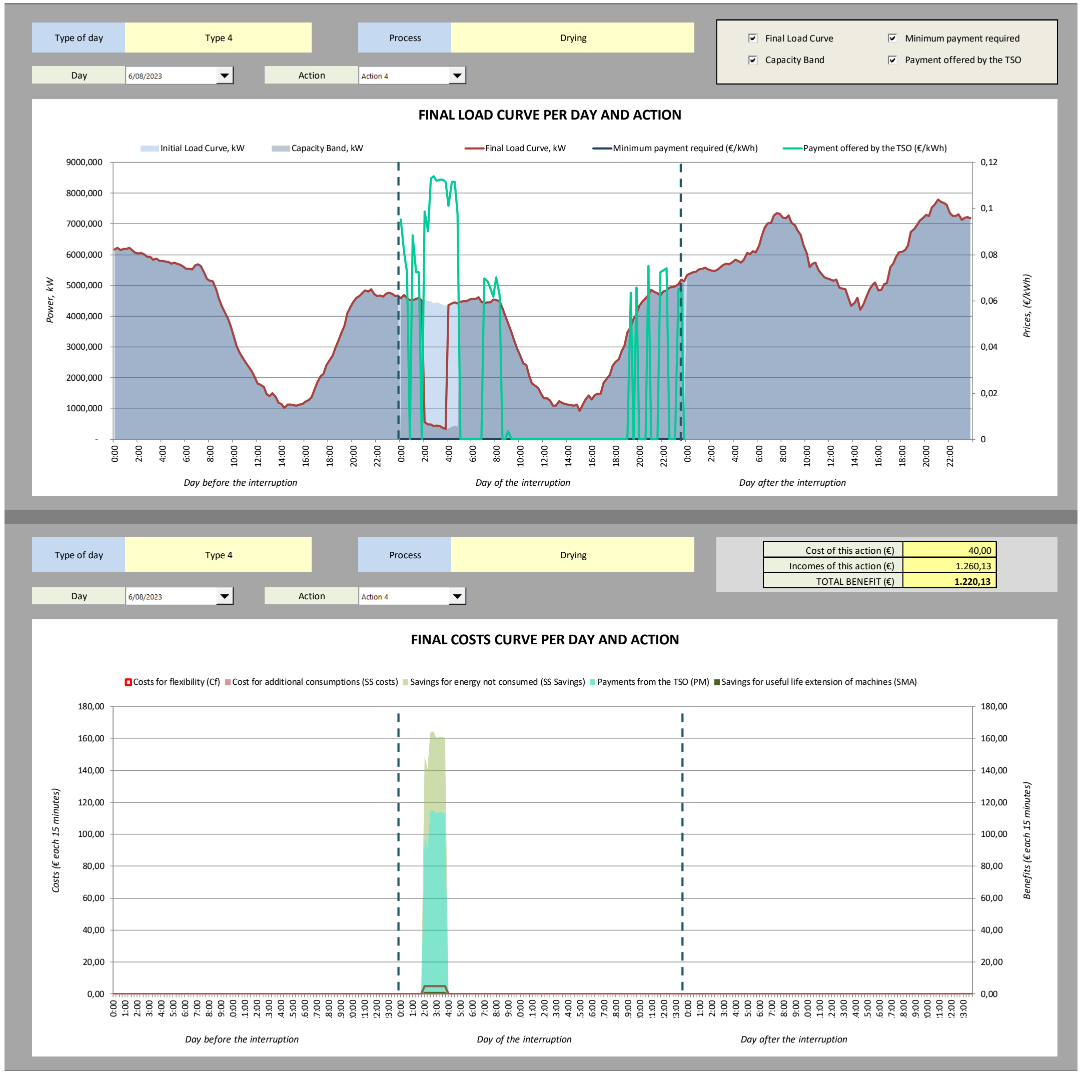
Type of day	Type 2	Process	Drying
Day	5/04/2023	Action	Action 2

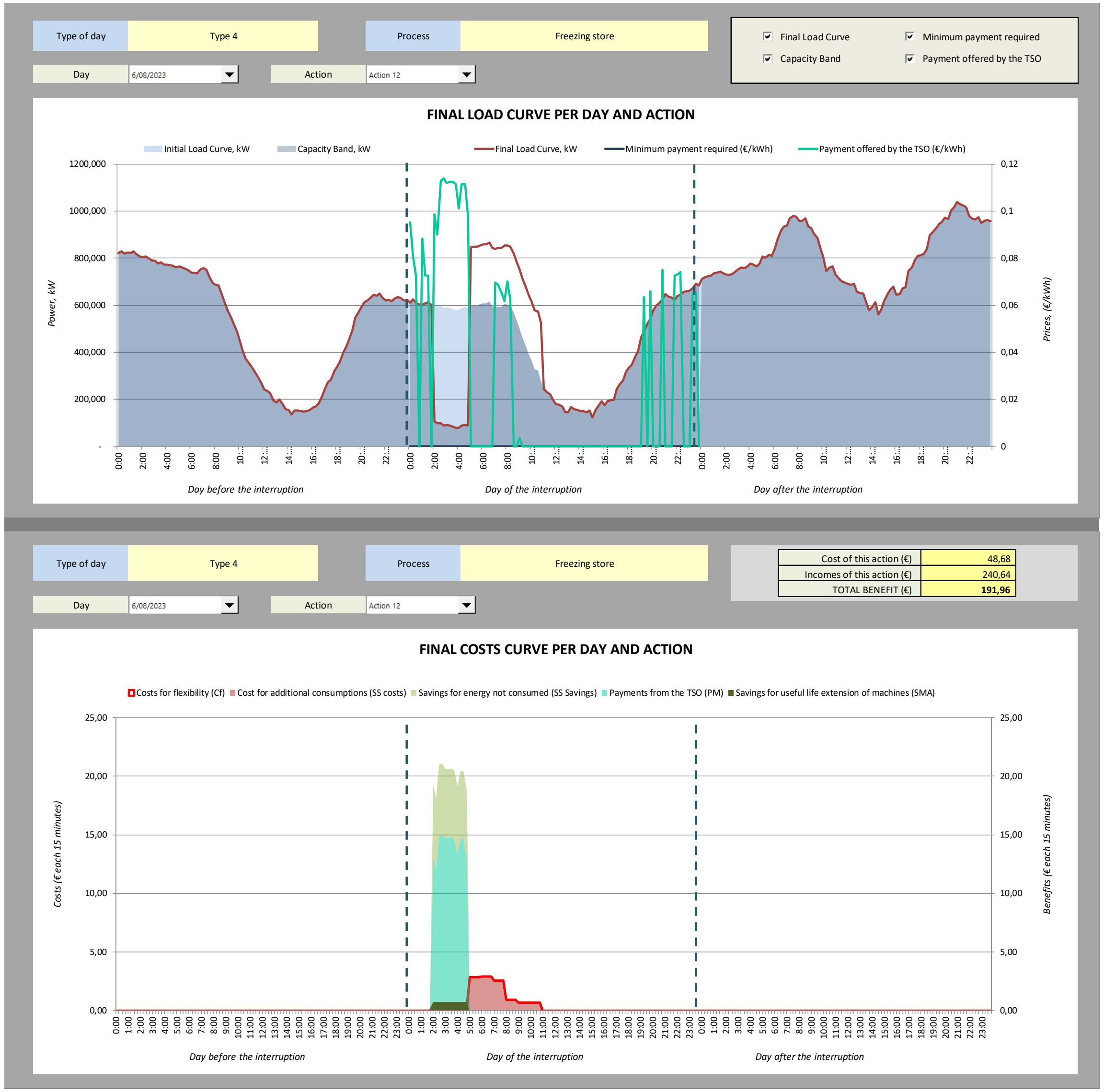
Cost of this action (€)	-
Incomes of this action (€)	-
TOTAL BENEFIT (€)	-

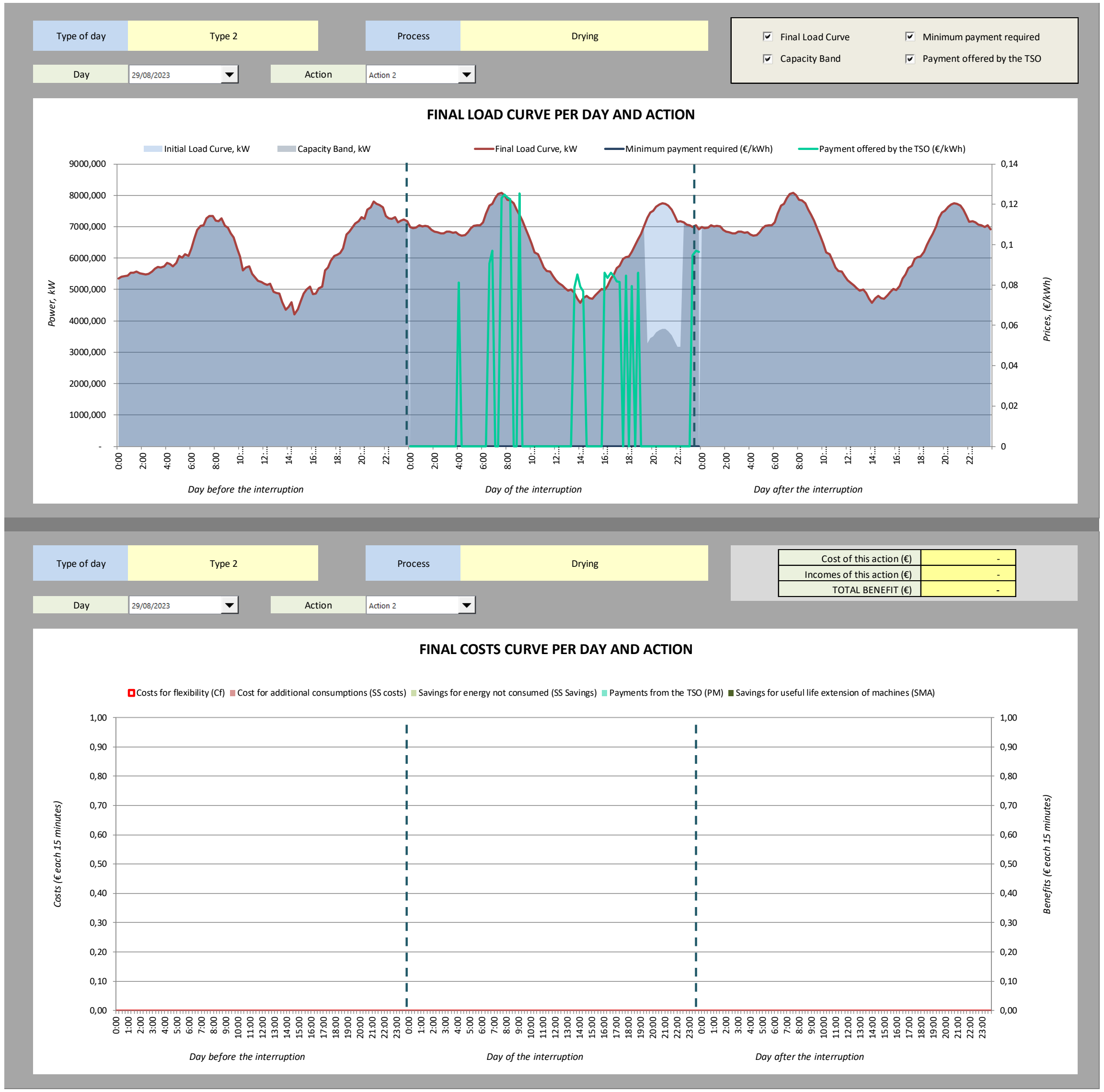


RESULTS FOR THE WHOLE MONTH - August 2023 (Tertiary reserve)

	Initial consumption	Final consumption	Energy balance	CO_2 balance	Economical energy balance (S_S)	Minimum payment required by customers (P_M^{min})	Payment offered by the TSO (P_M)	Margin of decission (P_M-P_M^{min})	TOTAL COSTS ($C_f + S_s^-$)	TOTAL INCOMES ($S_{MA} + S_S^+ + P_M$)	NET BENEFIT FOR THE CUSTOMER
	kWh	*kWh*	*kWh*	*tonCO₂*	*euro*	*euro*	*euro*	*euro*	*euro*	*euro*	*euro*
31/07/2023	385.710,2	385.710,2	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/09/2023	415.317,8	415.317,8	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/08/2023	415.317,8	413.077,8	2.240,0	0,19	334,79	6,93	297,99	291,06	230,82	856,23	625,40
2/08/2023	415.317,8	413.077,8	2.240,0	0,10	224,15	13,61	251,17	237,56	196,93	664,88	467,95
3/08/2023	415.317,8	413.077,8	2.240,0	0,13	204,64	16,83	269,26	252,44	200,99	667,52	466,53
4/08/2023	415.317,8	413.077,8	2.240,0	0,14	244,98	10,58	268,27	257,70	196,77	702,65	505,88
5/08/2023	251.827,8	250.737,8	1.090,0	0,12	118,39	0,17	123,30	123,13	61,13	299,13	238,00
6/08/2023	216.411,3	207.331,3	9.080,0	0,77	490,94	0,50	1.376,19	1.375,70	181,44	2.019,10	1.837,66
7/08/2023	385.710,2	382.350,2	3.360,0	0,25	247,13	4,09	409,15	405,06	211,40	856,63	645,22
8/08/2023	415.317,8	413.077,8	2.240,0	0,22	351,59	9,12	422,39	413,26	250,69	1.017,29	766,60
9/08/2023	415.317,8	411.867,8	3.450,0	0,56	659,64	4,43	679,97	675,54	376,67	1.705,22	1.328,55
10/08/2023	415.317,8	413.167,8	2.150,0	0,21	369,30	7,23	377,40	370,17	269,35	1.008,68	739,33
11/08/2023	415.317,8	413.077,8	2.240,0	0,23	429,31	5,92	457,80	451,88	271,14	1.150,88	879,74
12/08/2023	251.827,8	246.377,8	5.450,0	0,80	770,88	2,11	1.006,90	1.004,79	328,34	2.087,73	1.759,39
13/08/2023	216.411,3	207.601,3	8.810,0	1,13	1.105,23	1,71	1.199,53	1.197,82	329,30	2.604,71	2.275,40
14/08/2023	385.710,2	380.110,2	5.600,0	0,96	704,87	6,62	915,80	909,18	460,85	2.063,13	1.602,28
15/08/2023	415.317,8	413.077,8	2.240,0	0,20	400,29	8,74	425,55	416,81	270,26	1.088,73	818,47
16/08/2023	415.317,8	412.897,8	2.420,0	0,39	478,47	0,33	373,32	372,99	221,12	1.065,54	844,42
17/08/2023	415.317,8	413.257,8	2.060,0	0,20	410,89	5,24	355,63	350,39	303,76	1.062,91	759,15
18/08/2023	415.317,8	402.210,3	13.107,5	1,77	2.635,42	4,78	2.159,44	2.154,66	412,51	5.177,90	4.765,38
19/08/2023	251.827,8	253.315,3	-1.487,5	-0,15	-191,83	1,46	364,51	363,04	669,30	834,60	165,31
20/08/2023	216.411,3	214.231,3	2.180,0	0,43	351,42	0,17	354,22	354,05	144,18	842,44	698,27
21/08/2023	385.710,2	376.000,2	9.710,0	1,88	1.302,21	17,05	1.840,08	1.823,03	966,37	4.079,18	3.112,81
22/08/2023	415.317,8	413.317,8	2.000,0	0,36	511,74	6,65	448,93	442,28	349,25	1.302,54	953,29
23/08/2023	415.317,8	413.107,8	2.210,0	0,37	514,47	9,31	456,04	446,74	347,62	1.310,76	963,14
24/08/2023	415.317,8	413.077,8	2.240,0	0,34	496,46	10,77	523,74	512,97	332,91	1.345,75	1.012,84
25/08/2023	415.317,8	402.210,3	13.107,5	2,37	2.873,11	10,08	1.876,21	1.866,14	416,88	5.136,73	4.719,85
26/08/2023	251.827,8	246.190,3	5.637,5	1,20	793,36	2,57	1.651,38	1.648,81	1.008,72	3.423,97	2.415,26
27/08/2023	216.411,3	213.366,3	3.045,0	0,33	352,62	0,50	351,22	350,73	184,00	876,79	692,79
28/08/2023	385.710,2	383.470,2	2.240,0	0,26	278,15	3,84	319,29	315,44	198,40	788,46	590,07
29/08/2023	415.317,8	415.317,8	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
30/08/2023	415.317,8	413.077,8	2.240,0	0,20	443,98	7,51	382,22	374,71	283,77	1.102,59	818,82
31/08/2023	415.317,8	414.197,8	1.120,0	0,13	216,50	7,47	208,21	200,74	142,35	563,38	421,02
TOTAL MONTH	**12.107.864,0**	**11.991.363,9**	**116.500,0**	**16,10**	**18.123,13**	**186,30**	**20.145,12**	**19.958,83**	**9.817,23**	**47.706,05**	**37.888,82**

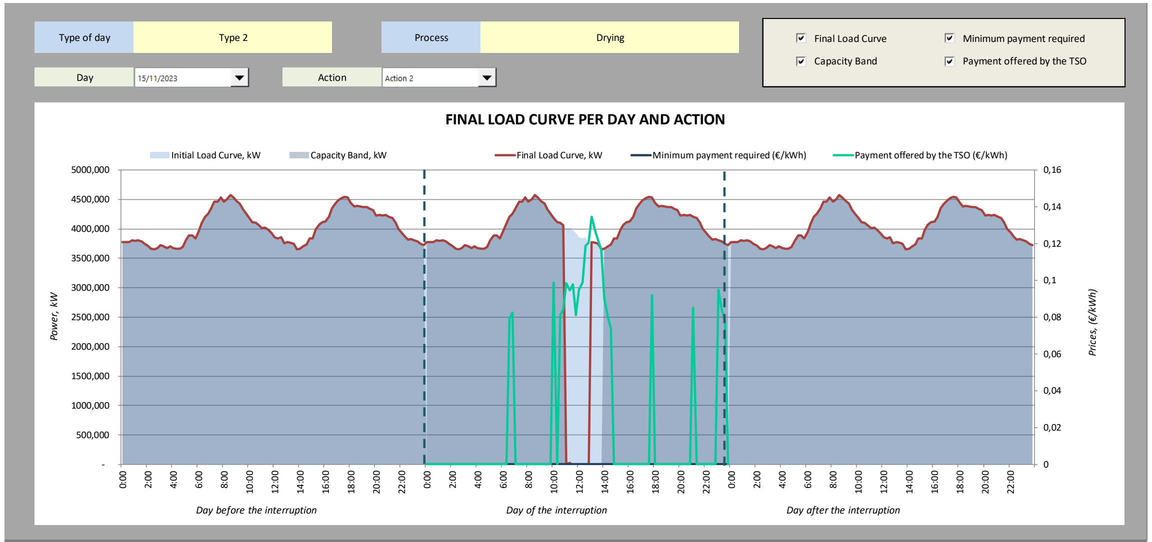

Type of day
Type 4
Process
Drying
Day
6/08/2023
Action
Action 4
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€) 40,00
Incomes of this action (€) 1.260,13
TOTAL BENEFIT (€) 1.220,13
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)

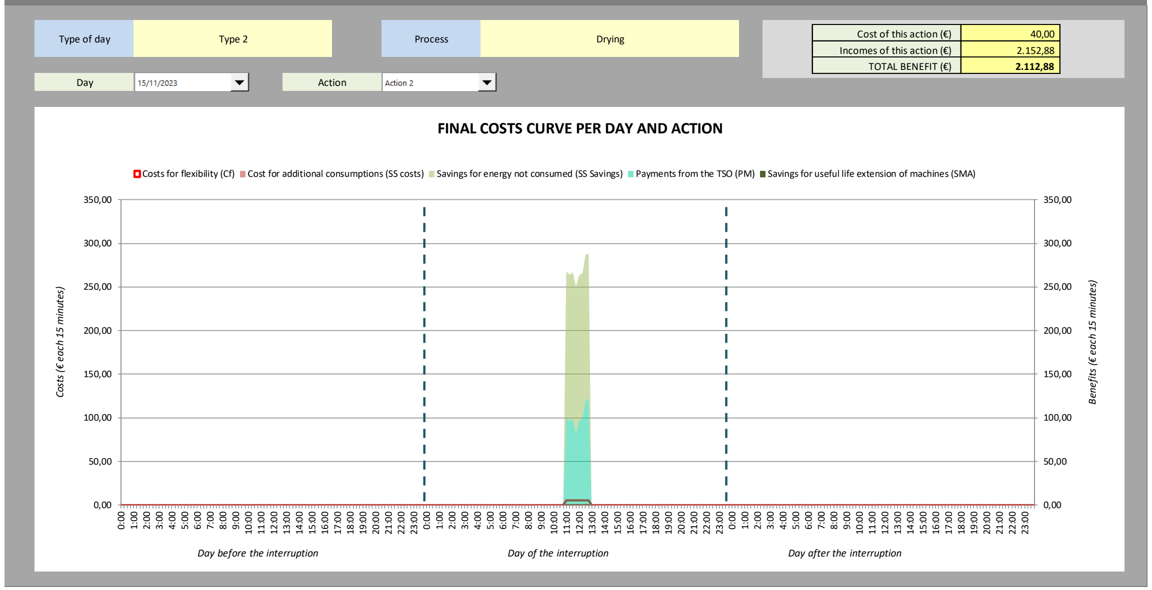

Type of day
Type 4
Process
Freezing store
Day
6/08/2023
Action
Action 12
Final Load Curve
Minimum payment required
Capacity Band
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€) 48,68
Incomes of this action (€) 240,64
TOTAL BENEFIT (€) 191,96
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)

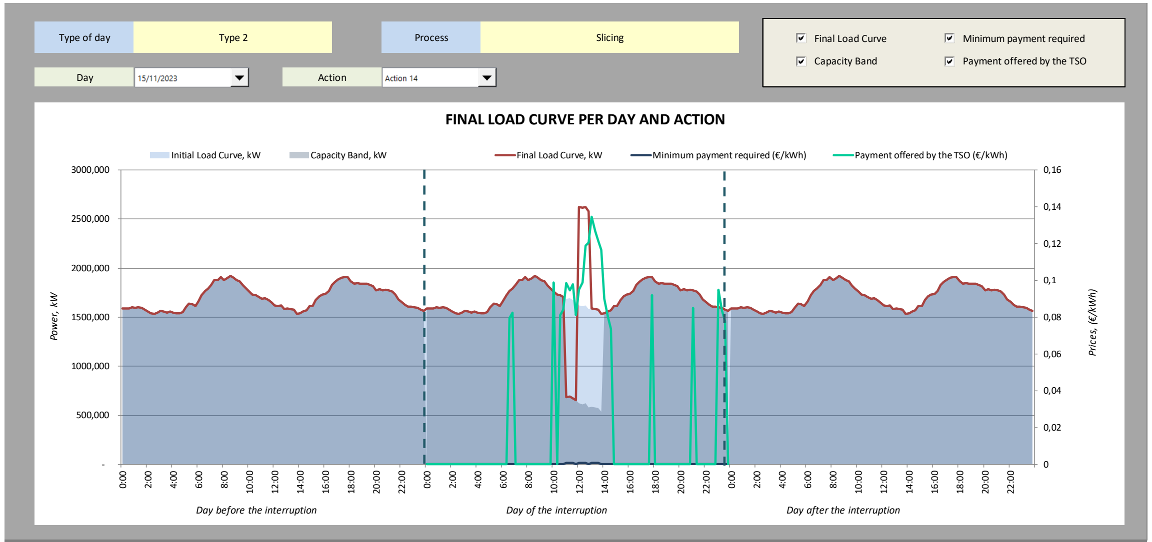

Type of day
Type 2
Process
Drying
Day
29/08/2023
Action
Action 2
Final Load Curve
Minimum payment required
Capacity Band
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€)
Incomes of this action (€)
TOTAL BENEFIT (€)
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)

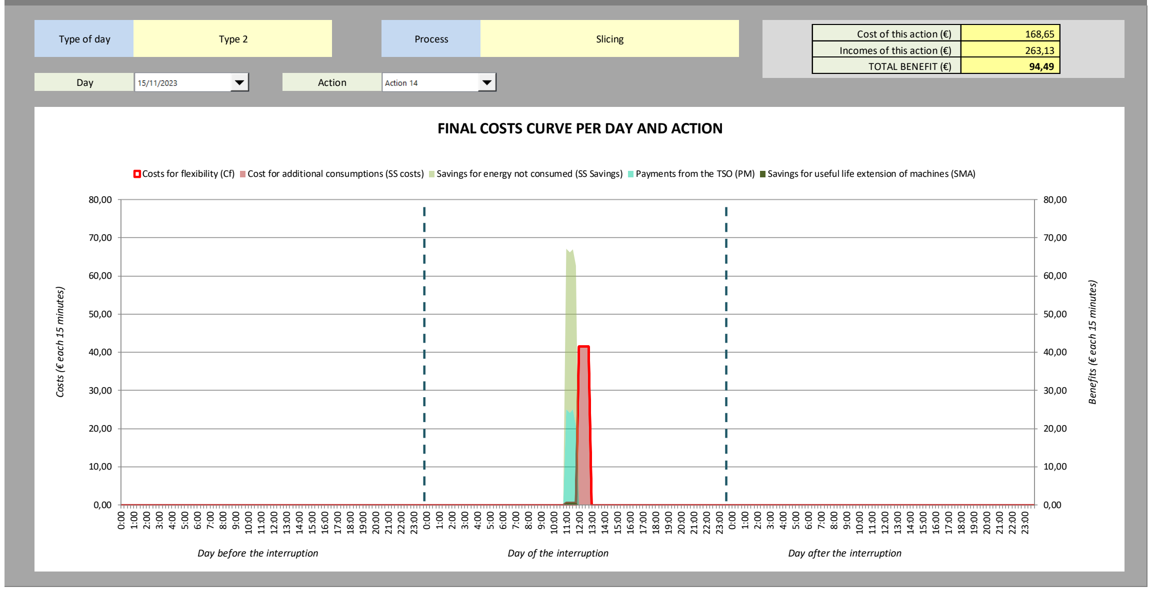
RESULTS FOR THE WHOLE MONTH - November 2023 (Tertiary reserve)

	Initial consumption *kWh*	Final consumption *kWh*	Energy balance *kWh*	CO_2 balance *$tonCO_2$*	Economical energy balance (S_S) *euro*	Minimum payment required by customers (P_M^{min}) *euro*	Payment offered by the TSO (P_M) *euro*	Margin of decission (P_M-P_M^{min}) *euro*	TOTAL COSTS ($C_f + S_S^-$) *euro*	TOTAL INCOMES ($S_{MA} + S_S^+ + P_M$) *euro*	NET BENEFIT FOR THE CUSTOMER *euro*
31/10/2023	426.210,5	426.210,5	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/12/2023	426.210,5	426.210,5	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/11/2023	426.210,5	415.810,5	10.400,0	0,43	381,44	0,50	296,30	295,80	200,95	849,22	648,27
2/11/2023	426.210,5	426.050,5	160,0	-0,01	35,33	0,17	29,54	29,37	43,73	104,91	61,18
3/11/2023	426.210,5	425.090,5	1.120,0	0,05	42,37	0,17	15,95	15,78	30,47	85,11	54,63
4/11/2023	271.827,6	269.827,6	2.000,0	0,12	19,27	0,50	46,52	46,02	20,14	78,95	58,81
5/11/2023	236.432,9	226.812,9	9.620,0	0,45	137,90	5,68	766,06	760,38	119,67	994,27	874,60
6/11/2023	404.762,6	401.092,6	3.670,0	0,24	-71,12	8,35	498,30	489,95	193,74	606,17	412,43
7/11/2023	426.210,5	426.210,5	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
8/11/2023	426.210,5	423.970,5	2.240,0	0,14	356,02	0,33	295,69	295,35	205,31	849,64	644,33
9/11/2023	426.210,5	423.970,5	2.240,0	0,11	283,92	0,33	235,18	234,85	130,02	641,75	511,73
10/11/2023	426.210,5	426.210,5	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
11/11/2023	271.827,6	264.827,6	7.000,0	0,38	127,76	1,56	157,72	156,15	77,16	338,37	261,21
12/11/2023	236.432,9	235.342,9	1.090,0	0,05	15,05	6,26	74,83	68,58	54,19	140,50	86,32
13/11/2023	404.762,6	400.282,6	4.480,0	0,35	152,41	5,43	235,15	229,72	237,41	610,22	372,81
14/11/2023	426.210,5	416.800,5	9.410,0	0,51	829,14	0,66	920,95	920,29	535,00	2.255,72	1.720,73
15/11/2023	426.210,5	416.140,5	10.070,0	0,68	1.642,26	0,50	1.534,06	1.533,56	892,66	4.039,50	3.146,84
16/11/2023	426.210,5	424.930,5	1.280,0	0,10	355,02	0,17	286,71	286,54	309,23	943,58	634,35
17/11/2023	426.210,5	425.090,5	1.120,0	0,09	244,87	0,17	171,66	171,49	140,59	553,42	412,84
18/11/2023	271.827,6	263.827,6	8.000,0	0,74	877,33	3,91	878,45	874,54	299,50	2.028,06	1.728,56
19/11/2023	236.432,9	234.252,9	2.180,0	0,14	164,53	7,88	240,32	232,44	110,54	508,02	397,48
20/11/2023	404.762,6	395.802,6	8.960,0	0,96	821,66	4,32	1.118,52	1.114,20	654,41	2.565,27	1.910,86
21/11/2023	426.210,5	421.730,5	4.480,0	0,20	355,88	0,50	372,14	371,65	184,28	897,55	713,28
22/11/2023	426.210,5	426.210,5	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
23/11/2023	426.210,5	426.210,5	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24/11/2023	426.210,5	422.850,5	3.360,0	0,19	395,08	0,50	434,32	433,82	232,25	1.050,59	818,33
25/11/2023	271.827,6	263.827,6	8.000,0	0,71	830,07	5,05	920,74	915,69	288,02	2.011,76	1.723,74
26/11/2023	236.432,9	234.252,9	2.180,0	0,24	322,80	5,70	354,46	348,76	159,46	829,35	669,88
27/11/2023	404.762,6	404.762,6	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
28/11/2023	426.210,5	421.730,5	4.480,0	0,51	986,29	0,50	673,44	672,94	516,58	2.161,56	1.644,98
29/11/2023	426.210,5	422.850,5	3.360,0	0,25	579,07	0,50	472,38	471,88	272,25	1.312,64	1.040,39
30/11/2023	426.210,5	420.610,5	5.600,0	0,43	1.112,33	1,65	722,08	720,44	564,02	2.380,05	1.816,02
-	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL MONTH	**12.176.302,0**	**12.059.801,7**	**116.500,0**	**8,04**	**10.996,66**	**61,25**	**11.751,45**	**11.690,20**	**6.471,56**	**28.836,16**	**22.364,60**


Type of day
Type 2
Process
Drying
Day
15/11/2023
Action
Action 2
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption


Type of day
Type 2
Process
Drying
Day
15/11/2023
Action
Action 2
Cost of this action (€) 40,00
Incomes of this action (€) 2.152,88
TOTAL BENEFIT (€) 2.112,88
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)
Day before the interruption
Day of the interruption
Day after the interruption

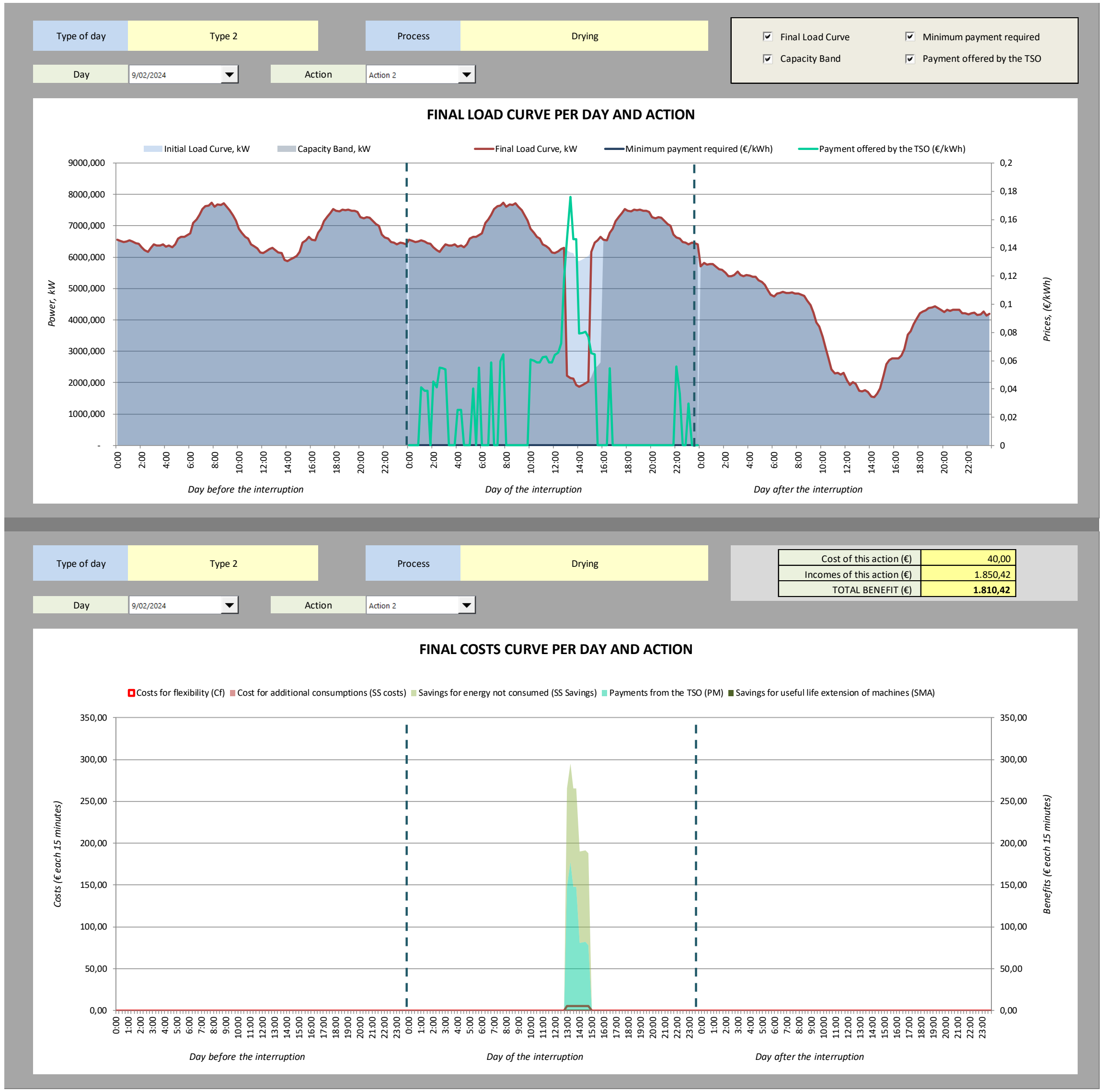

Type of day
Type 2
Process
Slicing
Day
15/11/2023
Action
Action 14
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption

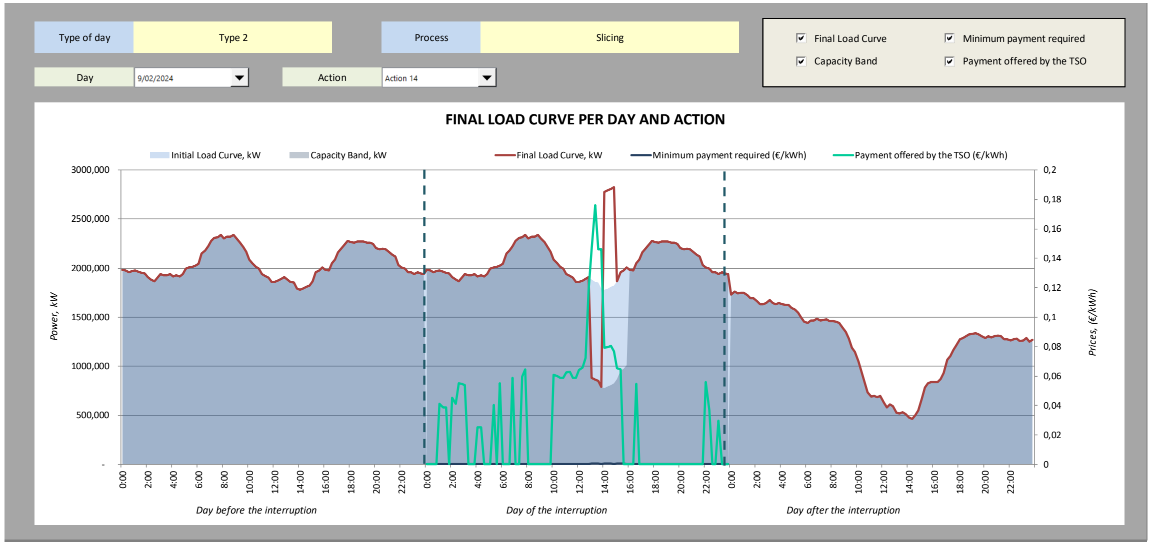

Type of day
Type 2
Process
Slicing
Day
15/11/2023
Action
Action 14
Cost of this action (€) 168,65
Incomes of this action (€) 263,13
TOTAL BENEFIT (€) 94,49
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)
Day before the interruption
Day of the interruption
Day after the interruption

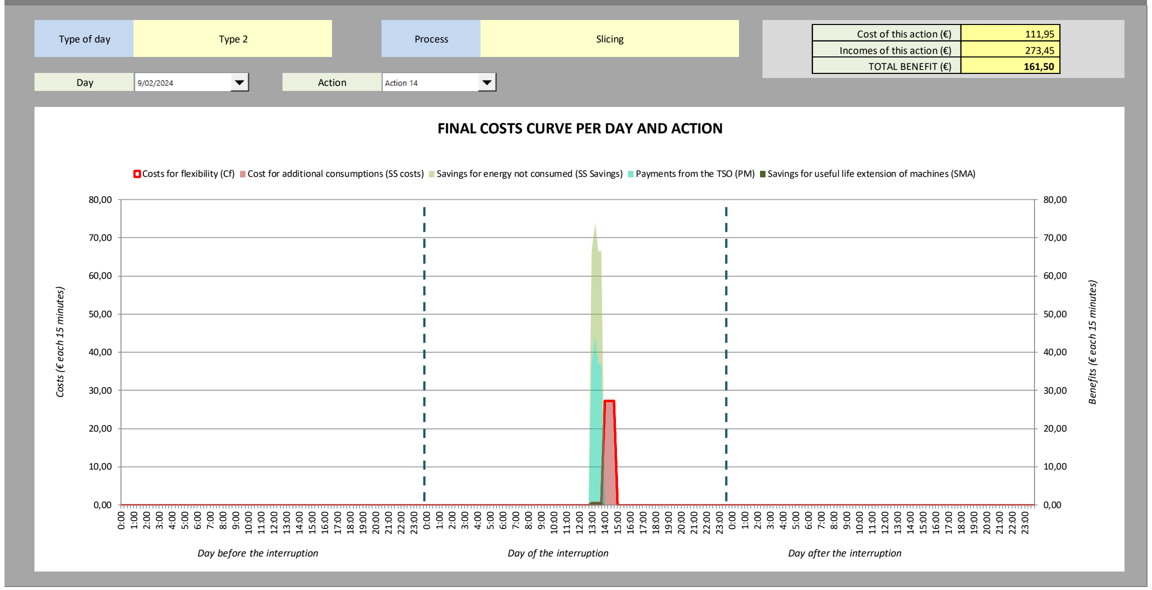

Type of day
Type 2
Process
Drying
Day
7/11/2023
Action
Action 2
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€)
Incomes of this action (€)
TOTAL BENEFIT (€)
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)

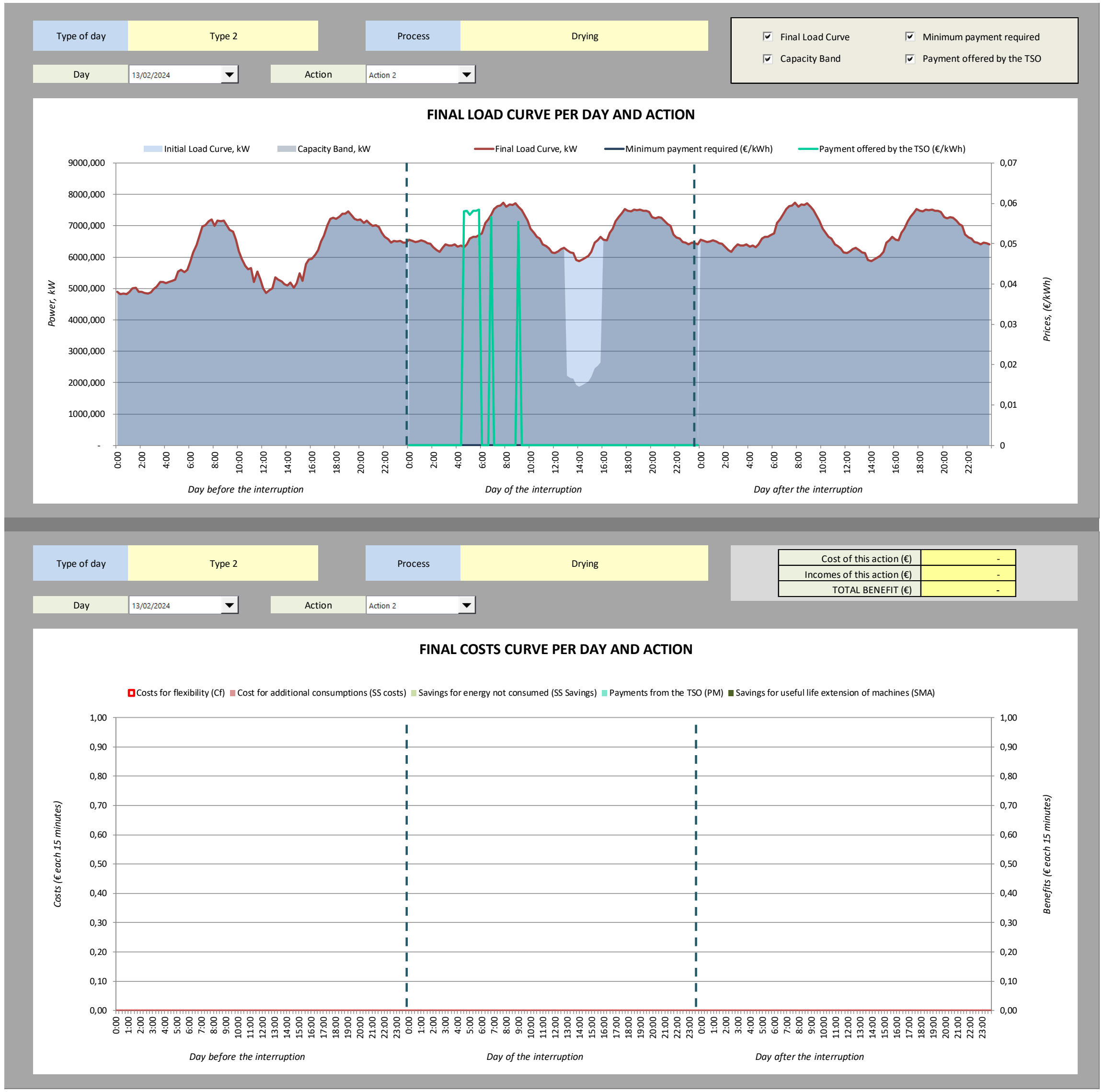
RESULTS FOR THE WHOLE MONTH - February 2024

	Initial consumption *kWh*	Final consumption *kWh*	Energy balance *kWh*	CO_2 balance *tonCO$_2$*	Economical energy balance (S_S) *euro*	Minimum payment required by customers (P_M^{min}) *euro*	Payment offered by the TSO (P_M) *euro*	Margin of decission (P_M-P_M^{min}) *euro*	TOTAL COSTS ($C_f + S_S^-$) *euro*	TOTAL INCOMES ($S_{MA} + S_S^+ + P_M$) *euro*	NET BENEFIT FOR THE CUSTOMER *euro*
31/01/2024	405.997,2	405.997,2	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/03/2023	405.997,2	405.997,2	0,0	0,0	0,0	-	-	-	0,0	0,0	0,0
1/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
2/02/2024	405.997,2	401.517,2	4.480,0	0,22	604,56	0,50	362,54	362,05	337,71	1.290,06	952,36
3/02/2024	241.658,6	238.388,6	3.270,0	0,25	237,47	3,14	266,79	263,65	140,67	633,87	493,21
4/02/2024	227.894,0	218.994,0	8.900,0	1,14	730,42	1,17	803,81	802,63	284,95	1.789,78	1.504,83
5/02/2024	362.543,1	355.463,1	7.080,0	0,67	872,28	11,64	759,31	747,66	653,16	2.262,72	1.609,56
6/02/2024	405.997,2	406.357,2	-360,0	-0,03	-33,74	0,00	0,00	0,00	33,74	0,00	-33,74
7/02/2024	405.997,2	395.357,2	10.640,0	0,41	918,31	3,11	847,73	844,62	572,54	2.309,10	1.736,56
8/02/2024	405.997,2	396.557,2	9.440,0	0,43	841,45	2,29	997,77	995,47	556,41	2.366,15	1.809,74
9/02/2024	405.997,2	397.217,2	8.780,0	0,51	1.067,42	0,50	1.600,94	1.600,45	562,15	3.201,12	2.638,96
10/02/2024	241.658,6	232.998,6	8.660,0	0,35	95,87	0,66	623,32	622,66	125,74	815,45	689,71
11/02/2024	227.894,0	219.354,0	8.540,0	0,68	450,31	1,52	709,37	707,85	268,61	1.398,88	1.130,28
12/02/2024	362.543,1	361.423,1	1.120,0	0,08	126,73	20,23	91,30	71,07	119,46	333,80	214,34
13/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
14/02/2024	405.997,2	404.877,2	1.120,0	0,06	128,97	0,00	92,78	92,78	66,75	284,82	218,06
15/02/2024	405.997,2	403.757,2	2.240,0	0,11	274,64	0,33	143,43	143,10	155,04	565,75	410,70
16/02/2024	405.997,2	404.877,2	1.120,0	0,07	130,48	0,17	73,03	72,87	73,82	273,65	199,82
17/02/2024	241.658,6	239.478,6	2.180,0	0,16	138,61	0,33	126,04	125,71	74,73	332,00	257,28
18/02/2024	227.894,0	225.714,0	2.180,0	0,19	140,73	0,33	138,18	137,85	63,39	334,94	271,54
19/02/2024	362.543,1	361.423,1	1.120,0	0,06	80,36	8,28	59,44	51,16	71,53	207,64	136,11
20/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
21/02/2024	405.997,2	403.757,2	2.240,0	0,11	174,05	0,33	105,77	105,44	115,50	387,95	272,45
22/02/2024	405.997,2	400.397,2	5.600,0	0,24	270,41	0,50	246,92	246,42	158,57	657,51	498,94
23/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
24/02/2024	241.658,6	239.478,6	2.180,0	0,11	40,37	0,17	66,52	66,35	30,13	129,64	99,52
25/02/2024	227.894,0	223.534,0	4.360,0	0,28	54,57	0,66	16,29	15,63	47,42	103,53	56,11
26/02/2024	362.543,1	360.303,1	2.240,0	0,10	73,28	0,17	8,17	8,01	46,13	120,10	73,96
27/02/2024	405.997,2	404.877,2	1.120,0	0,05	38,65	0,08	1,39	1,32	19,47	55,87	36,40
28/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
29/02/2024	405.997,2	405.997,2	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
-	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
-	0,0	0,0	0,0	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00
TOTAL MONTH	**11.042.330,0**	**10.944.079,9**	**98.250,0**	**6,22**	**7.456,20**	**56,10**	**8.140,86**	**8.084,76**	**4.577,62**	**19.854,33**	**15.276,71**


Type of day
Type 2
Process
Drying
Day
9/02/2024
Action
Action 2
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€) 40,00
Incomes of this action (€) 1.850,42
TOTAL BENEFIT (€) 1.810,42
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)


Type of day
Type 2
Process
Slicing
Day
9/02/2024
Action
Action 14
Final Load Curve
Capacity Band
Minimum payment required
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption


Type of day
Type 2
Process
Slicing
Day
9/02/2024
Action
Action 14
Cost of this action (€) 111,95
Incomes of this action (€) 273,45
TOTAL BENEFIT (€) 161,50
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)
Day before the interruption
Day of the interruption
Day after the interruption


Type of day
Type 2
Process
Drying
Day
13/02/2024
Action
Action 2
Final Load Curve
Minimum payment required
Capacity Band
Payment offered by the TSO
FINAL LOAD CURVE PER DAY AND ACTION
Initial Load Curve, kW
Capacity Band, kW
Final Load Curve, kW
Minimum payment required (€/kWh)
Payment offered by the TSO (€/kWh)
Power, kW
Prices, (€/kWh)
Day before the interruption
Day of the interruption
Day after the interruption
Cost of this action (€)
Incomes of this action (€)
TOTAL BENEFIT (€)
FINAL COSTS CURVE PER DAY AND ACTION
Costs for flexibility (Cf)
Cost for additional consumptions (SS costs)
Savings for energy not consumed (SS Savings)
Payments from the TSO (PM)
Savings for useful life extension of machines (SMA)
Costs (€ each 15 minutes)
Benefits (€ each 15 minutes)