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Table of Contents

Table of Contents	2
1 Introduction	4
2 Demand Side Management in multi-energy systems.....	5
2.1 DSM definition	5
2.2 Flexible loads.....	5
2.2.1 Thermostatically controllable loads.....	5
2.2.2 Deferrable loads.....	6
2.2.3 Loads supplied by multi-energy carriers.....	6
2.3 DSM objectives.....	6
2.4 Ways of implementing DSM.....	7
2.4.1 Energy efficient systems	8
2.4.2 Energy storage devices	8
2.4.3 Smart control	8
2.5 Market and business opportunities	10
2.5.1 Deployment of DSM in the market.....	10
2.5.2 Market barriers	11
2.6 DSM and user's engagement strategies.....	11
2.6.1 Introduction and theoretical aspects of social engagement	11
2.6.2 Methodological suggestions	15
3 DSM schemes in Osimio	17
3.1 Existing technologies to unlock flexibility	17
3.1.1 The CHP – DH plant.....	17
3.1.2 Energy flexible buildings	21
3.1.3 Water pumping station.....	23
3.2 New technologies to be installed for the DSM schemes	25
3.2.1 Smart Controller	25
3.2.2 Electric heating technologies.....	29
3.2.3 V2G and V2B technologies.....	31
3.2.4 Thermal energy storage.....	35
3.3 Data analysis.....	36
3.4 DSM schemes and objectives.....	40
3.4.1 The CHP-DH plant	41
3.4.2 Energy flexible buildings	41
3.4.3 Water pumping station.....	42
3.5 User engagement strategies	43
3.5.1 Astea's workers.....	43
3.5.2 DH users and PV panels owners	44
4 DSM schemes in Oud-Heverlee	45
4.1 Existing technologies to unlock flexibility	45
4.1.1 Mapping of assets in the neighbourhood.....	45
4.1.2 Description of the different technologies.....	45
4.2 New technologies to be installed for the DSM schemes	49
4.2.1 Smart Controller	49
4.2.2 Electric heating technologies.....	51
4.2.3 V2G and V2B technologies.....	51
4.2.4 Neighbourhood battery	53
4.2.5 Hybrid heat pump	55
4.3 Data analysis.....	56

4.3.1	Low-cost metering	56
4.3.2	High-quality metering	57
4.4	DSM schemes and objectives	59
4.4.1	Self-consumption maximisation and cost minimization for the community	59
4.4.2	Power quality optimization.....	62
4.5	User engagement strategies	63
4.5.1	Passive DSM	63
4.5.2	Active DSM.....	63
4.5.3	Overview of user engagement strategies	64
5	Conclusions	66

1 Introduction

This deliverable is aimed to analyse and plan the demand side management (DSM) schemes to be applied in each demo, taking into account peculiarities and technical constraints of each site. First of all, the present state of the demo sites is analysed and, in particular, flexibility provider instruments are identified and presented. Purpose of the present scenario survey is to highlight which kind of actions can be set up and which new devices can be installed effectively in the demos. Therefore, the new generation/storage infrastructure for each demo is illustrated, underling the technical specifications of the considered systems, advantages and limitations. It is worth mentioning that the two demo sites are different between them for technologies in place and type of users involved, and this aspect allows a good representativeness of real existing cases. Purpose of this project is, indeed, to propose an optimal control framework for multi energy systems suitable for different system configurations. Therefore, different technologies will be involved in each demo, but used with the same aim: accomplish the DSM objectives tailored for each local energy community.

In this document a preliminary data analysis is also performed, in order to highlight criticalities and issues to be addressed by the DSM schemes. As a result of the abovementioned investigation, the DSM strategies that can be implemented in each location, with a preliminary assessment of the level of flexibility expected aggregating and coordinating the different assets using the smart management system is provided. Eventually user engagement is preliminary considered already at this stage of DSM schemes conception.

2 Demand Side Management in multi-energy systems

In this section the theoretical concept of demand side management and the state of the art of demand side management instruments and strategies are presented with particular reference to multi energy systems, i.e. in presence of different generation assets, energy vectors and final users.

2.1 DSM definition

The term Demand-Side Management (DSM) was coined in the early 1980s by EPRI (Electric Power Research Institute) and it is defined as “the planning, implementation and monitoring of those utility activities designed to influence customer use of electricity in ways that will produce desired changes in the utility’s load shape, i.e., changes in the pattern and magnitude of a utility’s load.”¹. All programs intended to influence the customer’s use of energy are considered demand-side management and can be addressed to reduce customer demand at peak times, reduce energy consumption seasonally or yearly, change the timing of end-use consumption from high-cost periods to low-cost periods and increase consumption during off-peak periods.

Demand side management can contribute both to increase customer’s satisfaction and coincidentally produce the desired changes in the electric utilities load in magnitude and shape in order to match the available energy production. More specifically, DSM can introduce several benefits in the power system, such as (i) a reduced electric power generation margin commonly used to deal with peak demands; (ii) a higher operational efficiency in production, transmission and distribution of electric power; (iii) more effective investments; (iv) lower price volatility; (v) lower electricity costs and (vi) a more cost-effective integration of highly intermittent renewables².

Nowadays the term Demand Side Management is used in a broader sense and includes all actions addressed to modify the final user’s overall demand, not only the electrical one. To this broader definition is oriented the MUSE GRIDS project

2.2 Flexible loads

In order to be able to adapt the energy demand to the energy production, it is necessary to have flexible loads which somehow can adapt the energy use to the resources availability within certain limits. The correct implementation of a DSM strategy should maintain the same final service to the users. However, users should be involved into the DSM programs and made aware about their purposes, thus they can be willing also to change their habits, while maintaining an acceptable comfort level.

There are different kinds of flexible loads based on demand side technologies which contain various forms of storage. They can be used to affect the electrical load pattern seen by the electric power system without compromising the quality of the energy services provided to the end-consumer. They are described in the followings.

2.2.1 Thermostatically controllable loads

Thermostatically controlled loads are typical residential examples of flexible loads. They include heat pumps, refrigerators, electric storage heaters and air conditioners. They are systems driven electrically which deliver a thermal load, thus they represent a nexus between electric and thermal energy. Their flexibility comes from inherent thermal storage, for example into the building envelope, or with additional thermal energy storage (TES) systems.

¹ Gellings C.W., Demand-side management: Volumes 1-5, EPRI, Palo Alto, CA, 1984-1988.

² Strbac G. Demand side management: benefits and challenges. Energy Policy 2008;36(12):4419–26.

Small scale electric heating and cooling systems can be installed in large numbers in the built environment, so they are good candidates for demand response (DR) programs, i.e. programs to change the electric usage in response to certain price signals. A large group of these loads can be controlled to have a considerable impact on the overall power system, such as providing frequency reserves or peak shaving. Furthermore, the impact on the single user's thermal comfort is limited, especially if a large amount of aggregated loads take part into DR programs³.

2.2.2 Deferrable loads

A deferrable load is an electrical load that requires a certain amount of energy within a given time period, but the exact timing is not important; it can wait until power is available. Typical examples of deferrable loads are laundry machines and dish washers: they can be operated on the basis of a schedule suggested by the utility without too many restrictions for the final service. These devices can be easily switched on/off by means of control signals from a domestic supervisor or from an external signal. Even if the single device has generally a low power installed and a limited amount of energy used, the possibility of aggregating several of these devices provides a good energy reserve for the overall energy system.

Furthermore, electric vehicles can be included in this category, even if more restrictions are present on their timing to be refilled or discharged. The electricity storage on board represents a way to take electricity from the grid when a surplus is available or to inject electricity when a shortage is occurring. Also in this case with a critical mass of electric vehicles is possible to have a significant impact on the power system.

2.2.3 Loads supplied by multi-energy carriers

In a multi energy system a further source of energy flexibility is available and it comes from the interactions among the different energy carriers involved. Indeed, in presence of a multi energy system it happens that thermal and electric loads can be produced by different generators employing different fuels. By changing the operational strategies of the overall system it is possible to favour a fuel over another, produce more or less electricity and obtain heat as primary- or by-product in an energy conversion process. In such a way different objectives can be achieved with the management strategies, e.g. GHG (greenhouse gases) emission reductions, primary energy use reduction, electricity peak power shaving, etc. In this context a wider definition of energy flexibility is applicable and it refers to all the energy carriers involved. In the following, if it is not differently specified, we refer to DSM to provide flexibility to the electricity grid.

2.3 DSM objectives

DSM programs can be aimed at peak clipping, valley filling, load shifting and strategic conservation (Figure 1).

³ A. Arteconi, D. Patteeuw, K. Bruninx, E. Delarue, W. D'haeseleer, L. Helsen, Active demand response with electric heating systems: impact of market penetration, *Applied Energy* 177 (2016) 636–648

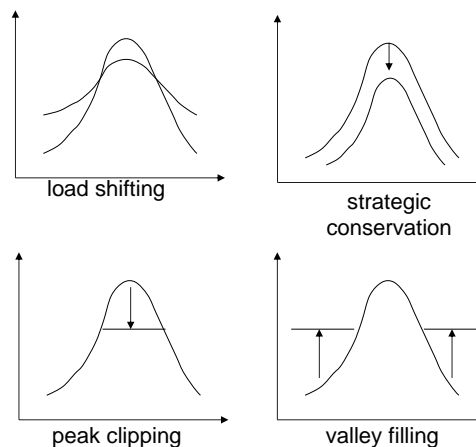


Figure 1. DSM strategies

- **Load shifting** means that the energy demand is moved to another moment in time. Typical load shifting strategies shift the energy demand from peak hours to off-peak hours. Generally, it is a strategy that can be applied in presence of an energy storage which allows the decoupling between energy demand and supply. Load shifting can be useful for example to achieve **market balancing** between available production and demand. It can also be used to solve **power quality** issue on the electricity network (load /frequency control). At user level, load shifting is helpful, for example, to increase the **self-consumption** of local RES (renewable energy sources) production.
- **Load conservation** refers to those DSM strategies aimed at reducing or limiting the overall energy demand while maintaining the same service level. The introduction of energy efficient devices helps to achieve such objective.
- The strategy of **peak shaving** aims to lower the peak demand, for example, by disconnecting some users (e.g. by temporarily reducing the production (or) by using on-site generation). This strategy helps to reduce the power plant installed capacity and new investments in further generation capacity by a better use of existing resources.
- On the other hand, it could be necessary for the correct management of the overall power system, that the energy demand during off peak hours is increased. In this way the energy demand variation with time is limited and the system management is easier: curve loads are flattened and the strategy is named **valley filling**.

2.4 Ways of implementing DSM

DSM technologies are used to unlock the energy flexibility in the considered energy system. They can be divided into three main categories: (i) energy-efficient end-use devices; (ii) additional equipment, systems, and controls to enable load shaping (e.g., energy storage, ES); and (iii) communication systems between end-users and external parties, for example, demand response (DR) programs. While the first point concerns energy conservation by means of devices using less energy, the other two points deal with systems aimed at shifting the final user's demand. Indeed, ES systems can be used to store surplus energy to be released for a later use, whereas demand response achieves changes in final users' load by means of price signals, as already explained above. Figure 2 shows the objectives achievable with the different DSM technologies.

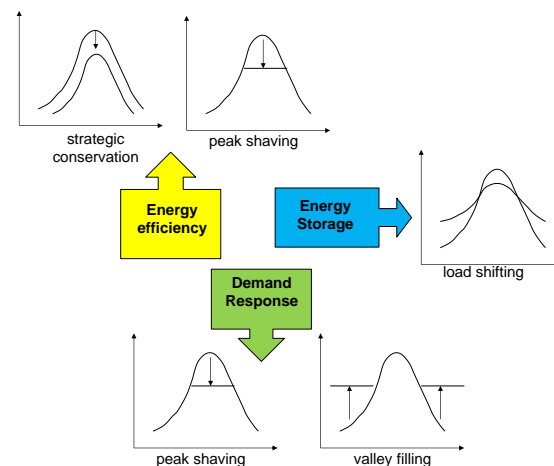


Figure 2. DSM instruments and possible strategies they make possible to implement⁴

2.4.1 Energy efficient systems

One way to implement DSM is to improve the energy efficiency of the involved devices. This improvement leads to lower energy consumption. There is therefore a lowering of the demand curve (load conservation), however this demand reduction is generally made on the whole curve not on a precise point. Thus a limited control is possible.

2.4.2 Energy storage devices

Energy storage systems are typically used to store energy in presence of a surplus and to release it in presence of a shortage: energy is stored to be used in a later moment. Thus the main effect which a thermal or electrical storage system can produce is load shifting to a different moment in time. Depending on the considered system and on its control strategy, the demand is moved to a different time slot to reshape the load curve as desired. Thermal energy storage systems can be made simply by thermally stratified water tanks (sensible TES) or by phase change materials (PCM). Different technologies are available for electric storage systems, among them EVs can also be included.

2.4.3 Smart control

DSM can work in two mainly different ways: direct and indirect control⁵. Direct control means that a contract is made with customers where the customer allows direct control over the power output. Indirect control means giving incentives to the customers based on different types of economic benefit that will motivate the customers to adapt their electricity use.

Even if in literature, several DSM techniques and algorithm can be applied in the context of reduction of system peak load demand and operational cost⁶, the strategies to be applied in smart grid need to handle a large number of variety of controllable loads. Here the mechanism of Demand Response is considered.

Demand Response is the tool mainly used to improve energy efficiency and reduce overall electricity consumption and it can be used to reduce power imbalances resulted due to penetration of renewable energies and other

⁴ A. Arteconi, F. Polonara, Assessing the Demand Side Management Potential and the Energy Flexibility of Heat Pumps in Buildings, *Energies* 2018, 11(7), 1846; ISSN: 1996-1073, doi: 10.3390/en11071846

⁵ H. Svahnström "Demand side management in Smart Grids" report, Gothenburg University, May 2013.

⁶ Kosek, A. M., Costanzo, G. T., Bindner, H. W., & Gehrke, O. (2013). An Overview of Demand Side Management Control Schemes for Buildings in Smart Grids. In 2013 IEEE International Conference on Smart Energy Grid Engineering (SEGE) IEEE. <https://doi.org/10.1109/SEGE.2013.6707934>

uncertainty resources.⁷ DR should be integrated into DSM to manage the electricity market and power system within both planning and operational timescales. DR can be defined as the changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time. Further, DR can be also defined as the incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized.⁸ Therefore, DR concerns any reactive or preventative method to reduce, flatten or shift demand. Historically, DR programs have focused on peak reduction to defer the high cost of constructing generation capacity. However, DR programs are now being looked to assist with changing the net load shape as well, load minus solar and wind generation, to help with integration of variable renewable energy. DR includes all intentional modifications to consumption patterns of electricity of end user customers that are intended to alter the timing, level of instantaneous demand, or the total electricity consumption.⁹ DR refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices). The implementation of DR actions is favoured by the installation of smart meters at the user's site, by the use of smart thermostats or smart white goods (dishwasher, fridge, washing machine etc..) and by the presence of communication channels with an external aggregator/utility to receive requests from the grid.

The demand-response programs can be divided in two main categorizes:

Load Response

There are three types of load response programs, generally incentive based:

Direct load-control programs — Primarily for residential and small commercial facilities with equipment, such as air conditioners, that may be "cycled" (turned off) for limited periods of time.

Curtailable load programs — Primarily for large commercial and industrial facilities that can reduce at least some of their load with a minimum threshold, such as 100 kW per event. Notification is generally from 30 minutes to two hours before the requested curtailment.

Interruptible programs — Primarily for industrial operations that can shed all or major portions of their load. Commercial facilities may also participate, particularly if backup generators can provide large portions of the load.

Price Response

Price response programs operate based on voluntary actions of electricity customers in response to market signals.¹⁰

Price response programs include the following:

- **Economic programs** — Primarily for *large commercial and industrial facilities* that can provide a minimum amount of load reduction, such as 100 kW per event. Participants may offer load reductions in certain amounts for certain time periods in response to a proposed price or set of hourly prices in the day-ahead market (or potentially the hour ahead or real time market). Payment is based on the market-clearing price in the day-ahead market bid by the participant and accepted by the buyer for day-ahead programs.
- **Time-of-use rates** — Eligible customers may be *residential, commercial, or industrial users*. Participation may be mandatory or voluntary depending on the jurisdiction. Special meters are installed to measure consumption during peak, off-peak, and in some cases, intermediate hours. Rates vary with time of day, day-of-week (since weekends are generally considered off-peak), and season of year (since winter

⁷ Javad Saebi, Mohammad Hossein Javidi "Implementation of Demand Response in Different Control Strategies of Smart Grids", Conference paper, January 2012

⁸ Balijepalli, Murthy; Pradhan, Khaparde (2011). "Review of Demand Response under Smart Grid Paradigm". IEEE PES Innovative Smart Grid Technologies.

⁹ Albadi, M. H; El-Saadany, E. F (2007). "Demand Response in Electricity Markets: An Overview". 2007 IEEE Power Engineering Society General Meeting. pp. 1–5.

¹⁰ "Demand Response Helps ISOs Lighten Load" — Transmission Insight, April 2002.

weekdays may be considered off-peak or intermediate hours). Rates are fixed for each period so the customer knows well in advance what the prices will be.

- **Real time pricing** — Primarily for *commercial and industrial facilities* with the ability to reduce or shift loads. Advanced communication systems allow electricity customers to observe real-time energy usage and forward prices. In one version, customers are provided hourly prices for the next day. Facility managers are free to maintain operations as planned or adjust operations to take advantage of lower rates. "Two-part" tariffs establish a baseline energy usage for each hour of the year. Baseline usage is agreed upon by both parties based on historical use subject to appropriate adjustments, such as changes in operations or weather. Variances in usage from baseline estimates are charged a premium if above, and a discount if below, the baseline using spot market clearing prices. An alternative to the two-part tariff is a "one-part" tariff that links all usage to hourly prices to market clearing spot prices and avoids baseline estimation.

2.5 Market and business opportunities

To fulfil the energy goals defined in Europe all the consumers must have the ability to benefit from their flexibility. This will require both *explicit* and *implicit* demand response that have been described in the previous section as load and price response respectively.

In explicit demand response schemes, also known as incentive-based, the aggregated demand-side resources participate in the wholesale, balancing and ancillary services and also in capacity mechanism where applicable. Consumers receive direct payments to change their consumption or generation patterns upon request, triggered by activation of balancing energy, differences in electricity prices or a constraint on the network. Benefits can be earned on an individual basis or collectively through an aggregator. It has been shown¹¹ that automatic demand control (load response) ensures that the electricity network can more flexibly respond to generation from weather-dependant resources. Through automatic demand control consumers can adjust their demand to match the available energy helping energy suppliers and network operators to better manage imbalance costs.

Implicit demand response (price response), sometimes referred to as price-based, is chosen by consumers who want to be exposed to time-varying electricity prices. Implicit demand response does not require the role of the aggregator.

Both types of demand response are complementary. They should be enabled together to fit all the customer's preferences and needs and to leverage the flexibility opportunities.

2.5.1 Deployment of DSM in the market

The independent aggregator represents a new role within European electricity markets. Defining the role of the aggregator is not an end in itself and will lead to several positive outcomes. The introduction of this role into a market creates critical momentum around the growth of Demand Response, attracts private investment, and fosters competition between service providers.

To enable independent aggregators to enter the market at scale, it is critical that the role and responsibilities of these new entrants are clarified. In particular, it is important that the relationships between retailers, balancing responsible parties (BRPs), and independent aggregators are clear, fair, and allow for fair competition between market parties. A regulatory framework should be put in place that is proportionate to the challenges faced by aggregators, and ensures that they can access the market without depending on the agreement of the consumer's retailer. Such a framework should define standardised processes for information flows on a need-to-know basis, as well as volume and financial settlements between the different market parties, with a view to avoiding any significant distortive impacts on the retailers/BRPs.

¹¹ Linear Project (<http://www.linear-smartgrid.be/en>)

2.5.2 Market barriers

The regulatory framework in Europe for Demand Response is progressing, but further regulatory improvements are needed: while the EU Demand Response market is further advanced than it was a couple of years ago, it is still fragmented. Cooperation between Member states can be seen within different regions in terms of cross border trade on the wholesale and balancing market, which is a positive sign. However, more work needs to be done to accelerate the promotion of Demand Response across all Member States. There are still major barriers (such as penalties, product requirements, consumer access, etc.) that need to be addressed before the EU can reach a harmonised Internal Energy Market.

Restricted consumer access to Demand Response service providers remains a barrier to the effective functioning of the market. Competition of service providers is essential to create the necessary market dynamics to access the full Demand Response potential. Nevertheless, regulatory frameworks in the majority of EU member states do not yet acknowledge the role of independent Demand Response aggregators, or they require aggregators to conclude bilateral contracts with retailers/BRPs – whose business is often competing – in order to sell consumers' flexibility. France and Switzerland are still currently the only countries to have a clear framework on the status of independent aggregators and their role and responsibilities in the market, while the UK, Ireland and Finland enable aggregator access at least to some markets and products. Progress can be seen in Belgium and Germany, where the definition of frameworks is under development, and discussions have started also in Austria and the Nordic countries.

The wholesale market must be further opened to demand-side resources: the issue of access for independent aggregators to the wholesale market is prevalent across the majority of Member States. In most cases, the framework only allows for BRPs or retailers to aggregate and sell their own consumers' flexibility. At best, some large consumers and Virtual Power Plants can sell their electricity directly on the market. This, alongside the further opening of the balancing market and ancillary services, needs to be addressed in order to allow for further competition between market actors in the electricity market.

2.6 DSM and user's engagement strategies

2.6.1 Introduction and theoretical aspects of social engagement

In the discourse about the energy transition, we always talk about the 'smart grid' as a technology project. However, ongoing problems with deployment of renewable energy have shown that implementation is largely determined by broad social acceptance issues¹².

Indeed, social acceptance is one of the key factors for the incorporation of any kind of innovation. It is a broad concept with multiple related aspects (communicative, economical, psychological, social, etc.) that must be taken into account when defining the social intervention model oriented to achieve social embrace.

Innovation acceptance, key for innovation integration

Classic theories about dissemination of innovation (Rogers, 1962¹³) suggest a working model around five stages (knowledge, persuasion, decision, implementation and confirmation). They consider the value of context and social networks to assure the incorporation of innovation (the so-called "social topology"), and also people's attitude towards innovation and everything around it (the innovators, the first adopters, the early majority, the lagged behind majority and the more traditional people).

Implemented policies or best technologies are not the only factors which will define the advance towards the energy democratisation; social and cultural changes are needed in order to give citizens a more active role,

¹² Wolsink, M. (2012). The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. *Renewable and Sustainable Energy Reviews*, 16(1), 822-835.

¹³ Rogers, Everett (1962); *Diffusion of innovations*; Free press.

empowering them to be able to decide not only about their consumption patterns but also about their energy generation and their energy system governance (Burke & Stephens, 2017¹⁴). This is a wide framework rooted on psychology, sociology or communication theories on which the effective search for citizens' commitment with technological innovations must be understood.

Paradigm shift: from energy consumer to energy citizen. State of the art

Energy transition processes must adapt the user engagement strategies for the implementation of technology innovation while considering the paradigm shift in the role of energy in our society.

The role of the consumer in the future energy model and smart grid will be prominent; however, the behavioural practices of consumers have been so far based on pricing signals. The support to the user engagement strategies has been based on the "behavioural economy" theoretical framework, considering that the user behaviour is based on their individual cost-benefit balance (Darnton and Evans, 2013¹⁵), without taking into account the social, technological or political context.

Despite the fact that the new role of the energy consumer is still not clearly defined, there are evidences about the need of a cultural paradigm shift for the energy transition to be guaranteed. Goulden, et al. (2014)¹⁶ identify two roles: energy consumers and energy citizens. In crude terms, the former is an end-user for whom energy-related practices are rather inflexible and for whom energy itself is of minimal presence. The latter corresponds with an end-user who engages with energy as a meaningful part of his or her everyday live. This author and others (Gram-Hanssen, 2011¹⁷) affirm that it is of vital importance to consider the active participation of the engaged citizens when designing smart grid projects as well as when defining energy efficiency in general.

The goal of the user engagement is to move the participants from the rigid energy consumer role to the flexible energy citizen role. Nevertheless, the most immediately accessible persona for end-users is that of the 'energy consumer'. Energy consumers consider energy just as one of multiple contingencies of daily life, with low priority compared to others such as work, family or finances.

As it has been pointed out, contemporary policy makers commonly approach energy demand issues with an individualistic model of attitudes and choices. Accordingly, *incentives* for shifts in energy behaviour are commonly framed in financial terms (i.e. lower bills). During conversations with focus groups, it was clear that most end-users are immediately responsive to such framing (Goulden, et al. 2014). However, this rather simple framing quickly becomes problematic: Would you delay cooking food for your children if this saved a few cents on your bill? Recent research (Dupont et al., 2011¹⁸) indicates that, in fact, dynamic electricity tariffs can generate savings of less than 3%, which does not seem to be a sufficiently strong signal to generate the desired changes.

The "*in-home displays*" (IHD) are instruments that have also been proposed as instruments to modify energy habits, by offering an undemanding means of becoming informed. However, it is important that the IHD shows information in very simple terms, instead of poorly understood metrics like kilowatt hours. The possibilities of an IHD in isolation are limited: over time, smart energy monitors gradually become 'backgrounded' with normal household routines and practices and, for a wide variety of reasons (among others, because they make it possible to visibly visualize

¹⁴ Burke, Matthew. & Stephens, JennieC. (2017); Energy democracy: Goals and policy instruments for sociotechnical transitions; in Energy Research & Social Science Volume 33, November 2017, Pages 35-48

¹⁵ Darnton, Andrew and Evans, David (2013); Influencing behaviours a technical guide to the ISM tool; The Scottish Government

¹⁶ Goulden, M., Bedwell, B., Rennick-Egglestone, S., Rodden, T., & Spence, A. (2014). Smart grids, smart users? The role of the user in demand side management. Energy research & social science, 2, 21-29.

¹⁷ Gram-Hanssen, K. (2011). Understanding change and continuity in residential energy consumption. Journal of Consumer Culture, 11(1), 61-78

¹⁸ Dupont, B. et al. (2011); Short-term Consumer Benefits of Dynamic Pricing; in 8th International Conference on the European Energy Market (EEM); 25-27 May 2011; Zagreb, Croatia.

the narrow limits of individual action), the monitors do not necessarily encourage or motivate households to reduce their levels of consumption (Hargreaves, Nye and Burgess 2013¹⁹; Verkade and Höffken²⁰).

A third group of instruments, *smartphone apps*, have also demonstrated their usefulness in modifying energy habits, provided they have additional (relevant, significant, understandable) information; at any rate, the context in which this information is incorporated by the user (educational level, coherence with other information, etc.) also limits their comprehension considerably. Long-term effects on energy attitudes are still been debated (Wood, et al., 2019²¹).

In short, all these antecedents show that motivations in energy-related habits in a household are much more complex than that captured by an individualistic framing. Financial inducements for ‘not cooking for your children’, for example, would have to be very significant to compel the consumer to consider them. Given the low gains that can be made with displacing the few kilowatt-hours of cooking, finding an economic basis for such an approach could be very challenging.

Trying to base the citizen engagement from merely informative instruments or that exclusively mobilize economic arguments and that appeal exclusively to the individual, collide with some notable limits that invite to promote other approaches and formulas that guarantee a greater consistency in the step to the action energy on the part of the consumer.

Contributions from environmental psychology

Indeed, human behaviours are not only explained by knowledge or cost/benefit balance. The Theory of Planned Behavior (Ajzen, 1991²²) from environmental psychology points out the important role that both personal attitudes and intention to act have on consumer behaviour: people only perform environmentally responsible behaviour when they are sufficiently informed about the problem they are acting upon, but also if they are motivated towards it, are able to generate changes that are not too difficult and observe that those changes are effective. Despite these evidences, several studies show that the correlation between attitudes and behaviours is small (Aragonés, 1997²³, Scott 1994²⁴): social research states that the presence of pro-environmental attitudes is a necessary, but not sufficient, condition to promote behavioural changes.

Social context and socialization of practices

In response to these paradigms that have impregnated some of the public policies aimed at modifying the energy habits of citizens but are limited when it comes to achieving desirable results, new theoretical frameworks are emerging in the last decade that are not looking at the individuals but in the practices, not so much at the people as at communities, since the changes of behaviours are conditioned by context, socioeconomic environment, social values and attitudes and capacities of the people. ICT-based energy monitoring and managing devices are specific tools that enable a better understanding and control of domestic energy behaviour and decision making. These technologies operate on the basis that they provide new information and/or instructions to individuals, who, having received the information, will change their respective energy usage behaviour accordingly. This individual, positivist and technology centred approach to understand energy usage has been challenged by the social sciences. Especially

¹⁹ Hargreaves, T., Nye, M., & Burgess, J. (2013). Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. *Energy policy*, 52, 126-134.

²⁰ Nick Verkade, Johanna Höffken (2017). Is the Resource Man coming home? Engaging with an energy monitoring platform to foster flexible energy consumption in the Netherlands, *Energy Research & Social Science*, 27, 36-44

²¹ Wood, G. et al (in press); Sensors, sense-making and sensitivities: UK household experiences with a feedback display on energy consumption and indoor environmental conditions; in *Energy Research & Social Science*, Volume 55, September 2019, Pages 93-105.

²² Ajzen, I. (1991); The theory of Planned Behavior. In *Organizational Behavior and Human Decision Process*, 50, 179-211.

²³ Aragonés, J. I. (1997). Actitudes proambientales: algunos asuntos conceptuales y metodológicos. In R. García-Mira, C. Arce y J. M. Sabucedo (Eds.), *Responsabilidad ecológica y gestión de los recursos ambientales* (pp. 137- 146). A Coruña: Diputación Provincial.

²⁴ Scott, D. y Willits, F. K. (1994); Environmental attitudes and behavior. in *Environment and Behavior*, 26, 239-260.

Practice Theory as a line of thinking has questioned the rationalist approach to how people relate to energy.²⁵ Gram-Hanssen (2011) proposes Practice Theory to understand change and continuity in residential energy consumption. Practice Theory helps to provide a new lens that focusses on what people do and tries to understand their practices in a broader context. It puts people in the center rather than technologies; it also tries to understand what people do – which informs – amongst others- the (in)effectiveness of DSM policies

Besides this theoretical framework, two additional frameworks seen suggestive for designing proposals for promoting user engagement: on the one hand, the "Low-Carbon Lifestyles and Behavioural Spillover" (Whitmarsh & O'Neill, 2010²⁶) raises the hypothesis that, in order to produce new consistent pro-environmental actions, two preconditions arise: that they are perceived as a consequence of one's own choice (and not to coercion) and that are conceptually linked with other actions already known and executed by the individual. On the other hand, the ISM (Individual, Social and Material) Tool launched by the government of Wales (Darton & Evans, 2013) to promote low carbon habits: a tool that tries to integrate the principles of the 'Behavioral Economy', Social Psychology and Practice Theory to propose the design of more effective social interventions.

The step into action and the participatory approach

Another school of thought can help us to complete the theoretical framework necessary for social intervention aimed at achieving user engagement: in the Participatory Approach, pro-environmental action does not arise from an imposition or a rote learning, but rather it is a "constructed action" (Breiting, 1997²⁷) in which the user become a co-protagonist of the innovation process and collaborates in the design of the solutions to the environmental and technological problems collectively analyzed. The Participatory Approach (Heras, 2002²⁸) has proved to be particularly valid in processes with a high degree of uncertainty, where solutions are not yet defined and spaces for creativity and social innovation are useful. The participatory practices, with a remarkable tradition in the field of territorial planning and the design of public policies for sustainability, can provide a particularly valuable community perspective when working in specific areas with defined identities in which the sense of belonging (Vidal & Pol, 2005²⁹) is an important methodological support, can facilitate the adequate management of conflicts (Elcome & Baines, 1999³⁰) and provides legitimacy to the decision-making (Subirats, 2001³¹).

Taking into account these approaches, and specifically integrating the contributions of Practice Theory, Environmental Psychology and the Participatory Approach, we propose below some methodological suggestions for the elaboration of messages and a series of action proposals that should serve to achieve the engagement of the potential users for both site demonstrators.

²⁵ Nick Verkade, Johanna Höffken. Collective Energy Practices: A Practice-Based Approach to Civic Energy Communities and the Energy System, Sustainability 2019, 11(11), 3230;

²⁶ Whitmarsh, L. & O'Neill, S. (2010); Green identity, green living? The role of pro-environmental self-identity in determining consistency across diverse pro-environmental behaviours. In Journal of Environmental Psychology.

²⁷ Breiting, S. et al. (1997); Plantando árboles; in Carpeta del CENEAM; Ministerio de Medio Ambiente.

²⁸ Heras, F. (2006): Entretantos. Guía para dinamizar procesos participativos sobre problemas ambientales y sostenibilidad; Ed. GEA coop.

²⁹ Vidal, T. & Pol, E. (2005); La apropiación del espacio: una propuesta teórica para comprender la vinculación entre las personas y los lugares. in Anuario de Psicología, 36, 281-297.

³⁰ Elcome, D & Baines, J. (1999); Steps to succes. Working with residents and neighbours to develop and implement plans for protected areas. IUCN Commision on Education and Communication; European Committee for EE. Suiza.

³¹ Subirats, J. (2001); Nuevos mecanismos participativos y democracia: promesas y amenazas. In J. Font (coord.) Ciudadanos y decisiones públicas. Ariel.

2.6.2 Methodological suggestions

Before defining the proposed actions to achieve the engagement of users in the project, we present some methodological notes to take into account both for the writing process of the messages and for the design of actions. We state them as reminders, as a check-up list that can be used in the preparation phase of action proposals.

On the way to elaborate messages:

- Simplify the message: either it is easy to understand (and to do), or you will not be able to persuade almost anyone to do it. If you can not explain what you want to get from the people you are addressing in a tweet, do not do it: make a new attempt to summarize it.
- Integrate reason, emotion and social intelligence, and more emotion and social intelligence than reason. Few of our acts are explained by "rational" motives and, without disregarding the need for argumentation and rigor, it is the emotion, values and attitudes that most often explain the things we do.
- Use peripheral messages: people are more likely to get involved with something that does a celebrity, a neighbour or see on the notice board of the local parish. They find it written on a flyer or an expert explains it. And it will be even more likely if you encounter the message in several places and in different contexts.
- Whatever it is, make it relevant: linking it with the needs of the people. In talks and presentations, look for ways to associate what you want to say with what people have said and / or are concerned about. It is convenient to know them previously: always a listening attitude.
- Not only information: Even if they seem fascinating, avoid focusing in the technological issues; not everyone is interested and few experts understand them. Focus on the benefits or the reasons for its application.
- Relate it to the context: it connects the implication of the user with the acts of thousands and thousands of people in the world committed to fight against climate change. It is not just an individual or collective act but is part of a global movement to move towards a decarbonised world. It is not only about improving the electrical networks or energy systems: it is actively working for the sustainability of the Planet.
- People are protagonists: no matter how much technology we apply, if people decide not to participate, the changes will not be effective. Therefore, we must appeal to people, even graphically, that men and women appear in the materials and communication devices that are used.

About the means and supports:

- Socialize the message. Locate it in different contexts, in environments of habitual socialization to normalize it. It shouldn't seem just a matter of technicians and people outside the community. Be aware to integrate the message in a proper way in the context.
- It matters who relates: Identify the social preceptors of the communities in which the demonstrator will be implemented. It will be valuable if people with a social impact in the community from different areas (social, cultural, sports, educational, ...) make their support for the project visible.

On the mobilizing arguments:

- Collaborating for the common good: the benefits of participating in this project are not for the electrical system or for the distribution company. They are for the participants, for the community and for the Planet.
- Beyond home: The benefits of collaborating in this project transcend the limits of each person's home. They are global (collaborate in the best market penetration of renewables) and community (improve the comfort of close people)
- It is not (only) a matter of money: Although there may be economic savings, these benefits are secondary. We must point out them, but it is important to put them in a secondary role compared to the rest.

- Prestige the change: Change is good, it has value and it is relevant to give it importance. It is what makes the world advance. When society requires urgent changes, it is valuable to have courageous people pointing out the path to the others.
- Sense of belonging: As a collective project, identified with the city in which it is going to develop, it is of interest to rely on the identity values of each locality to reinforce the importance of the project.

On the way of relating:

- Sequence communication actions: integrating the theoretical models on which this proposal is based, defines motivation activities (we have a problem); knowledge (deepen into causes and consequences), reflection (recognize change) and participation / action.

3 DSM schemes in Osimo

3.1 Existing technologies to unlock flexibility

The Osimo demo site is represented by the whole town of Osimo (~35,000 inhabitants), in Italy. It has just one point of connection with the national grid/TSO. The microgrid of Osimo is characterized by several distributed generation technologies; in particular: a 1.2 MWe CHP plant with a gas engine serving a district heating (DH) network of roughly 1250 users; more than 30 MWp of PV; 400 kW of mini-hydro; a 200 kW plant fed by liquid biomass; two biogas plant for a total power production of 2 MW. In Osimo, there is also an early stage programme of electric vehicles (EVs).

In this context three different DSM instruments have been identified to be used in the project demo. They have been selected for their flexibility potential with the purpose of considering key elements of interconnection among the different energy systems available in the local energy community of Osimo. They are:

1. The CHP – DH plant
2. Energy flexible buildings
3. A water pumping station

3.1.1 The CHP – DH plant

Technical specifications

The CHP plant, by producing both electricity and thermal energy, represents an instrument to provide flexibility to the electricity grid and that can interact with the natural gas grid.

The CHP plant is composed of a natural gas engine cogeneration system with an electrical nominal power of 1.2 MWe and a thermal power of 1.3 MWth. The thermal energy is used to supply a DH network (of about 444 m³ of water) by means of a plate heat exchanger (PHX). The DH network is composed of two circuits. The secondary circuit is disconnected by the primary circuit by means of another plate exchanger located in a water pumping station (town center). The plant is also equipped with natural gas boilers (2 boilers of 4.6 MWth and 1 boiler of 4.2 MWth, one of them used as back up) which provide additional thermal energy when the demand exceeds the CHP plant capacity. Recently a heat pump (HP) has been also installed in the CHP plant in order to recover the waste heat coming out from the low temperature engine cooling system. The heat recovered at about 40°C is used as low temperature source for the HP. The heat pump can uplift the temperature level of the DH returning water and provide useful heat to the DH at the condenser side (working at about 65-70°C). It is a two stage heat pump with a nominal thermal capacity of 160 kW and an average COP of about 4.6 (refrigerant R134a). It has been designed to work in parallel with the CHP plant without negatively affecting its performance. The heat pump is driven by the electricity produced by the CHP system itself.

Figure 3 shows the plant schematics, while Table 1 summarizes the generators power rate in the CHP plant.

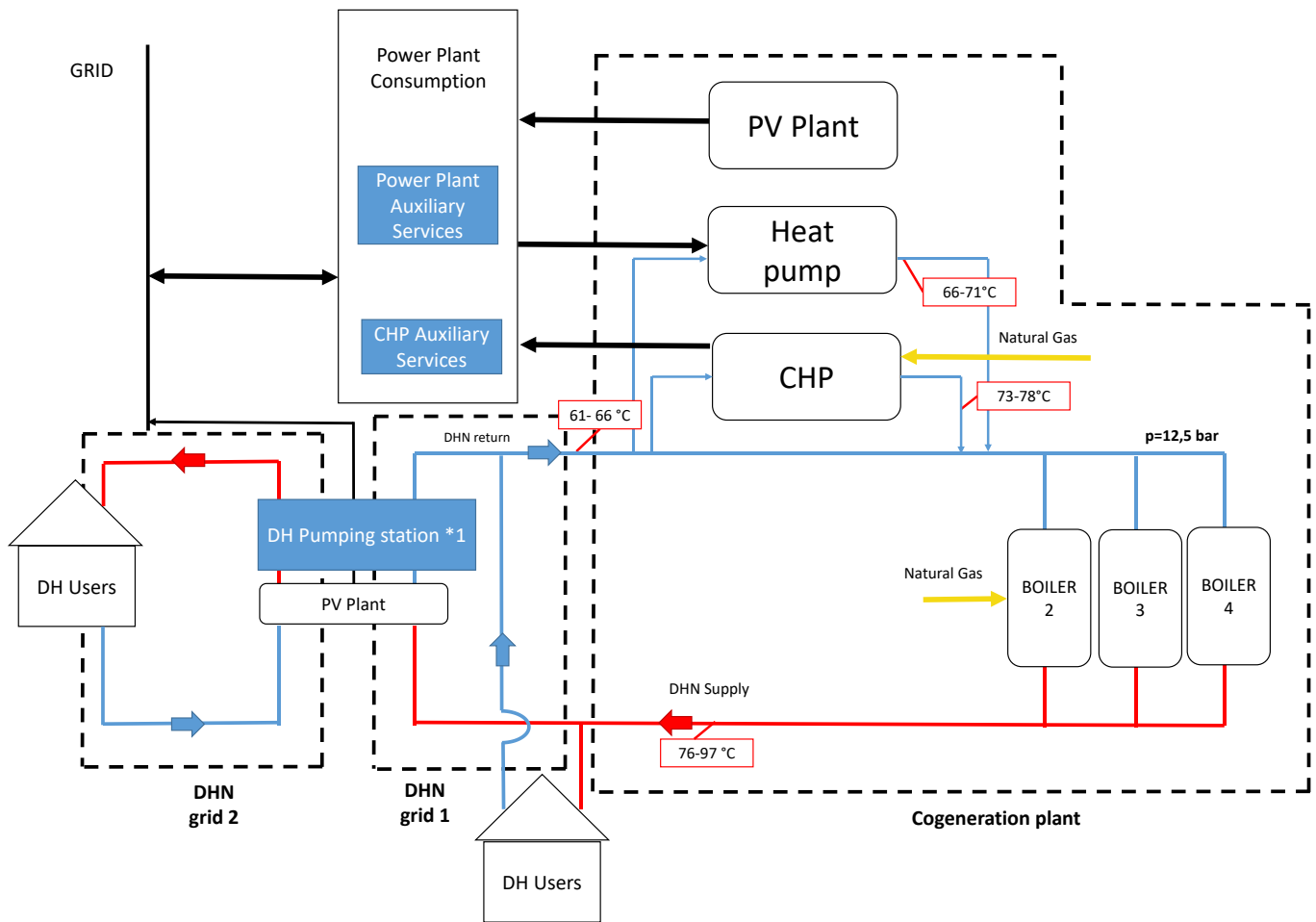


Figure 3. CHP-DH plant schematics

Table 1. CHP plant technical specifications

Generator	Nominal electric power (kW)	Nominal thermal power (kW)
Gas engine	1200	1300
Gas boiler	-	13500 (including back up)
Heat pump	34.8	160
PV plants	18.69	

Control strategies

The heat load is supplied to the DH network at different temperatures, varied accordingly with season. In Figure 4 the daily thermal demand in different seasons is shown: a large difference between winter demand and summer demand (only for domestic hot water, DHW) is highlighted.

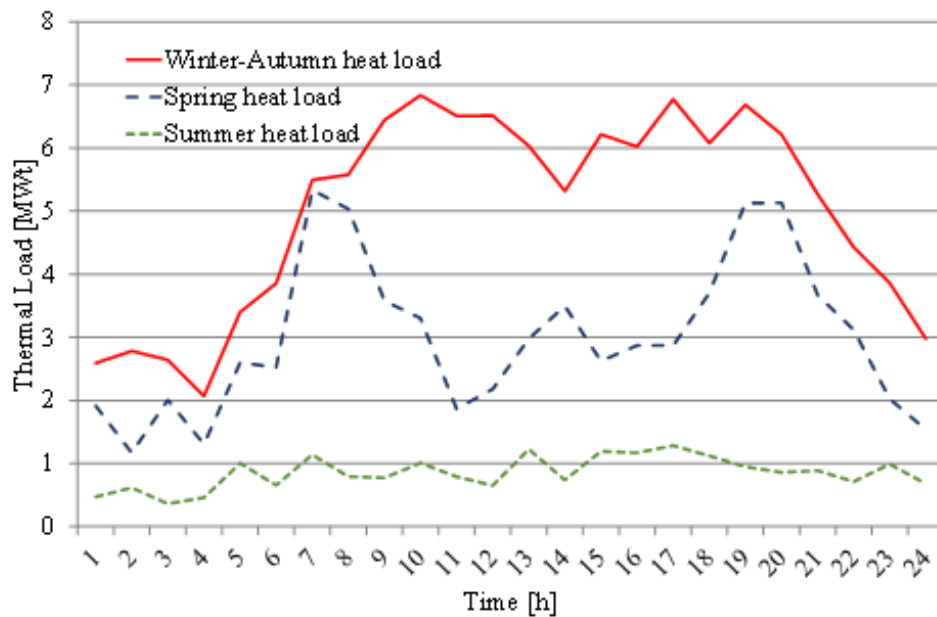


Figure 4. Trend of typical daily heat demand with varying the season.

The supply water temperature is adjusted in the different seasons to compensate the demand and the thermal losses with a rule of thumb method. In winter (November-March) the supply water temperature is 95°C and the engine is always on together with the boilers, which provide additional demand and increase the maximum temperature achievable by the engine. During mid-season (April- mid June and mid-September-October) the supply water temperature ranges between 78°C and 85°C, the engine modulates its load on the basis of the demand (its load can be reduced down to 80% of the full capacity) and the working schedule is between 7:00 am and 20:00 pm. Boilers are on if needed. In summer the engine is off and the thermal load is produced entirely by the boilers at 75°C.

At the moment, the CHP plant is operated in order to fulfil the DH thermal demand and, in particular, the working strategy of the gas engine cogeneration system is aimed at maximizing the achievable national incentives (base on primary energy saving, PES, that has to be >10). In Figure 5 it is possible to see the share of natural gas used by the gas engine cogeneration system and by the gas boilers: on a yearly basis they use the same amount of primary energy, but during summer only the gas boilers work, while in mid-season the engine has the priority over the boilers.

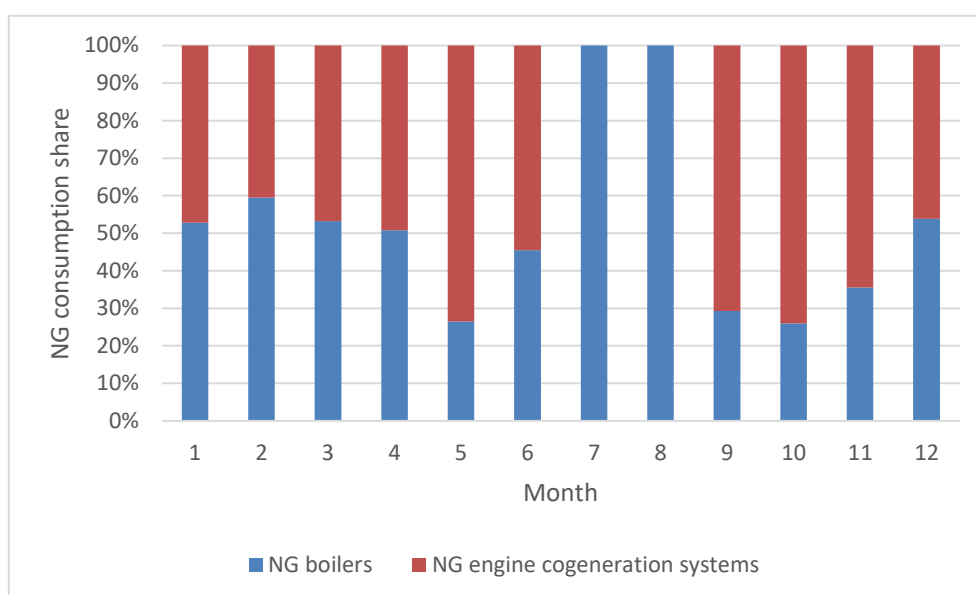


Figure 5. Natural Gas (NG) consumption share by the engine cogeneration system and boilers in the CHP plant (2018).

In Table 2 the energy performance of the CHP plant is reported.

Table 2. CHP plant performance in 2018.

	THERMAL ENERGY PRODUCED [kWh]	THERMAL LOSSES [kWh]	NG USED [Sm3]	PRODUCED ELECTRIC ENERGY [kWh]	ELECTRIC ENERGY INJECTED INTO THE GRID [kWh]	ELECTRIC ENERGY TAKEN FROM THE GRID [kWh]	SELF- CONSUMPTION [kWh]
JAN	3,102,500	620,910	485,576	881,943	815,655	0	66,288
FEB	3,441,800	605,086	511,272	798,281	734,407	160	63,874
MAR	3,116,400	683,065	479,196	857,687	793,699	768	63,988
APR	1,326,400	528,253	208,824	388,723	365,782	13,428	22,941
MAY	868,200	459,846	166,894	464,364	438,031	9,120	26,333
JUNE	694,600	407,630	112,130	230,660	216,372	13,956	14,288
JULY	596,300	375,865	64,920	0	0	21,708	0
AGO	568,600	361,002	62,267	258	214	18,304	44
SEPT	669,100	388,181	128,139	340795	320559	10,040	20,236
OCT	888,000	454,274	169,092	464065	439176	12,272	24,889
NOV	1,953,900	507,307	342,623	842135	788703	464	53,432
DEC	3,250,500	591,729	498,430	879590	810816	488	68,774
	20,476,300	5,983,148	3,229,363	6,148,501	5,723,414	100,708	425,087

The overall energy efficiency of the CHP plant when the gas engine works spans between 84% to 88%.

In the plant there is also a photovoltaic (PV) plant with a nominal electric power of 12.6 kW. Figure 6 shows the global electricity balance of the integrated generation system and PV plant. Especially in mid-season, when the engine works at part load and not for the all day, some of the electricity necessary to run the auxiliaries is taken

from the grid. In July and August when the engine cogeneration system is off, the PV electricity is completely self-consumed, but it is not enough to cover all the demand for the plant needs.

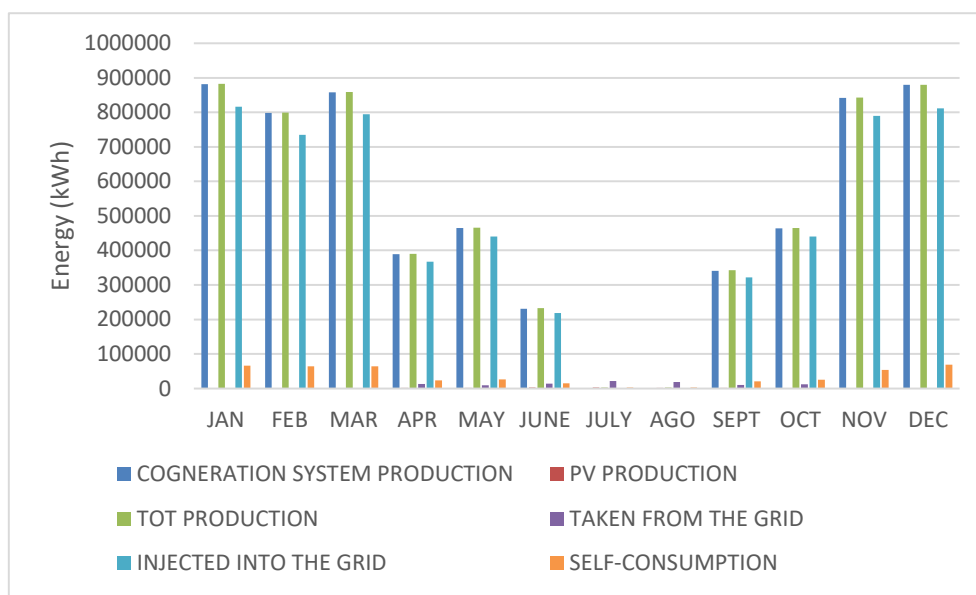


Figure 6. Electricity balance for the integrated CHP + PV plant (2018).

Furthermore, there is another PV plant with a nominal electric power of 6.09 kW in the DH pumping station to cover the electricity demand for pumping: the renewable energy produced is almost completely used (the electricity injected into the grid is less than 3% of the total electricity produced). Figure 7 shows the electricity balance of this PV plant.

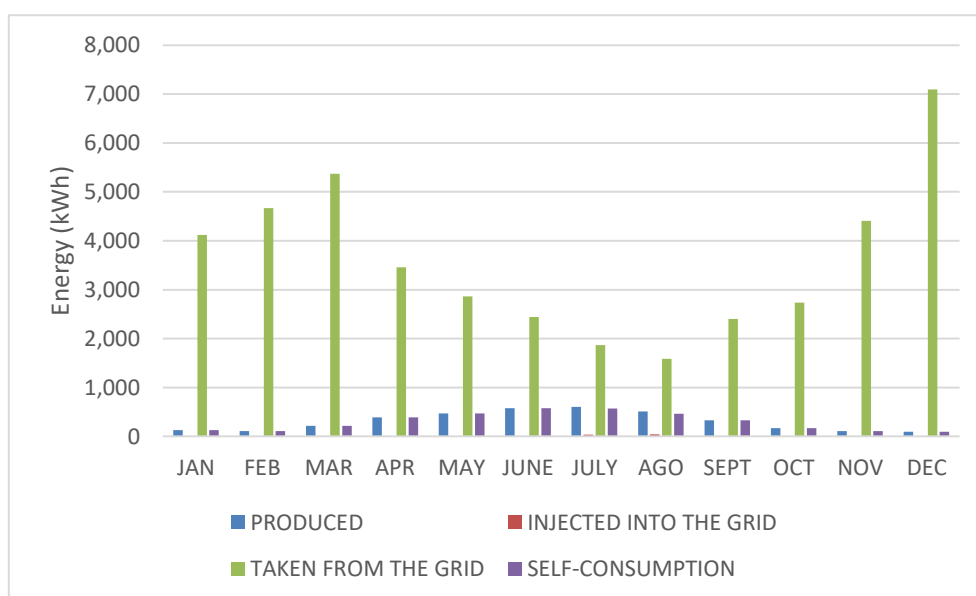


Figure 7. PV plant production in the DH pumping station (2018).

3.1.2 Energy flexible buildings

The second asset to be used to implement DSM schemes is represented by the flexibility provided by buildings through their inherent thermal energy storage in the building envelope and through the use of flexible electric heating systems installed in Astea's office buildings. With more detail the Astea's headquarter in Osimo and the

office in the CHP plant are considered as representative examples of commercial/tertiary buildings. Even in this case there are interactions both with the electricity grid and with the natural gas grid.

Technical specifications

In the headquarter in Osimo the following technologies are present:

- 4 electric boilers for DHW (about 1500 W)
- 2 gas boilers for space heating, only one works, the other one is a back-up. The thermal power is 580 kWth and 600 kWth respectively.
- 1 air handling unit for space heating and cooling.
- 1 refrigeration unit with R22, 103 kW of nominal electric power input
- 1 central control system for the indoor thermal comfort
- 1 heat pump (Panasonic Multitype air conditioner with R410A) used for space heating and cooling only of a new part of the building. Heating thermal capacity 25 kW and electric power 6.22 kW; cooling thermal capacity 22.4 kW and electric power 5.89 kW.
- 1 EVs charging station (3kW electric power) and two electric vehicles with an energy storage capacity of 22 kWh each (charging time 6-9 hours).
- PV panels with a nominal electric power of 31.39 kW.

At present in the office located in the CHP plant there are the following devices to provide space heating and cooling and DHW:

- 1 electric boiler to produce DHW
- 1 reversible air-to-water heat pump for space heating and cooling with 2 split systems
- Manual control system to adjust indoor temperature set-points

Control strategies

In Figure 8 it is possible to see the PV electricity production in 2018 for the plant in the headquarter building: the plant is new and the production starts only in August. In this case all the electricity produced is used to cover the building demand and the injection into the grid is very low (always lower than 4% of the electricity produced).

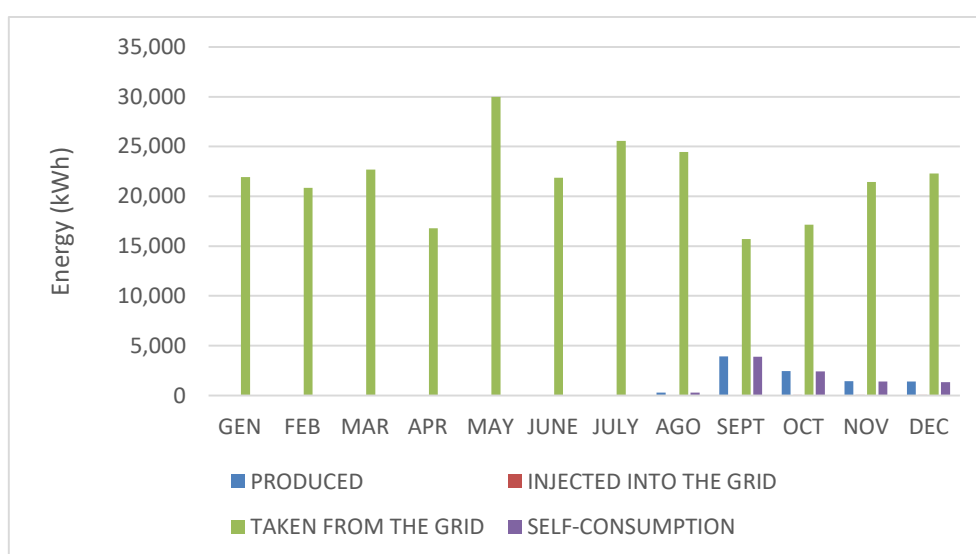


Figure 8. PV electricity production for the plant located in Astea's headquarter building (2018).

In Figure 9 it is possible to see the overall electricity consumption for Astea's headquarter building. It includes lights, computers, electric boilers, chiller for air conditioning and heat pump of the new part of the building, auxiliaries of natural gas boilers system. The electricity demand has a base load throughout the year, due to lights, while it reaches its maximum values in summer when cooling is required. The figure shows also the thermal demand produced by natural gas boilers for heating of the main part of the building.

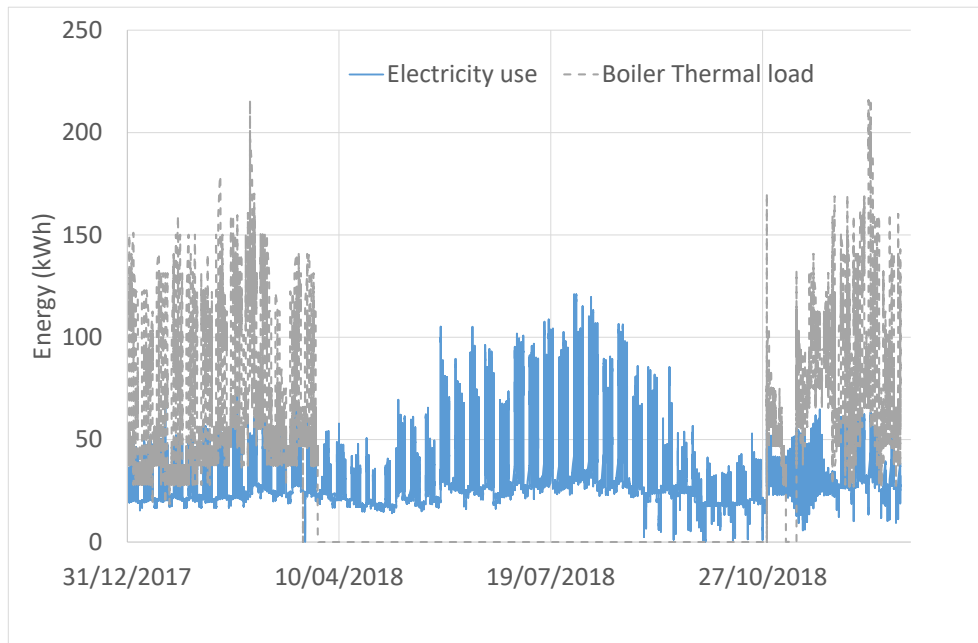


Figure 9. Astea's headquarter energy use (2018).

No detailed data are available for the office in the CHP plant.

3.1.3 Water pumping station

A water pumping station of the water network is also considered as part of the demo activities. In this case the interaction between the electricity network and the water network can be explored.

Technical specifications

The pumps are used to lift the water pressure in order to overcome the pressure drops in the water network. Two pumps, as reported in the schematics in Figure 10, with a nominal electric power of 200 kW each (only one works, the other is a back up), send the water from the main reservoir to a smaller water tank serving some districts of the town.

In this pumping station a PV panel plant with a nominal electric power of 15.08 kW is installed.

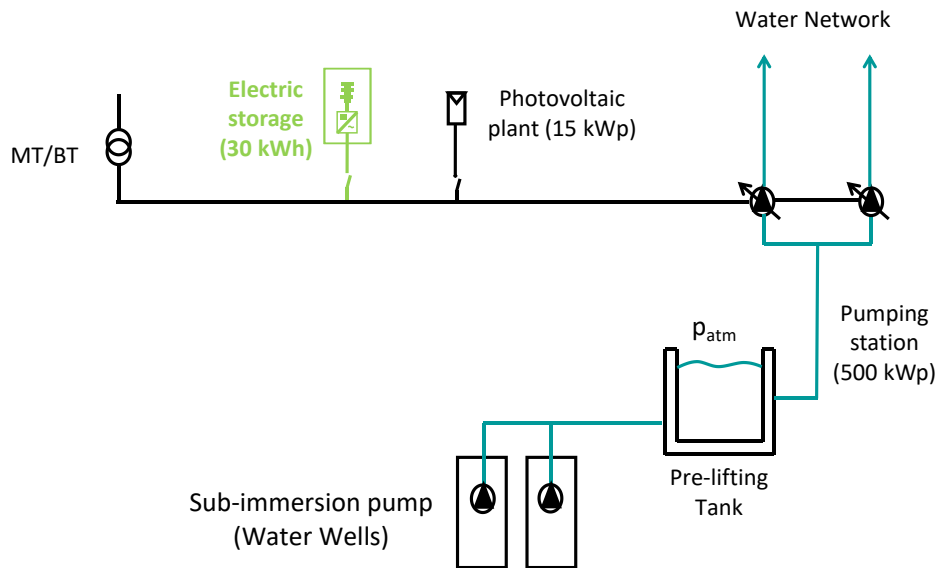


Figure 10. Pumping station layout (in green a new device installed into the project, as discussed in Section 3.4).

Control strategies

The pumps of the water pumping station are switched on to maintain the water level into the reservoirs (Figure 10) into a given range. The necessary electricity is taken from the grid and partially produced by the local PV panels. The electricity produced by PVs is used to cover the electricity demand for pumping water, however at the moment the self-consumption ratio is about 90%, but it could be increased if flexibility instruments were employed (Figure 11). In Figure 12 it is possible to see a typical day when the PV electricity is injected into the grid. Even if the overall daily electricity demand is higher than the production, due to non-simultaneity between the two, part of the renewable electricity has to be injected into the grid, even if the power is limited.

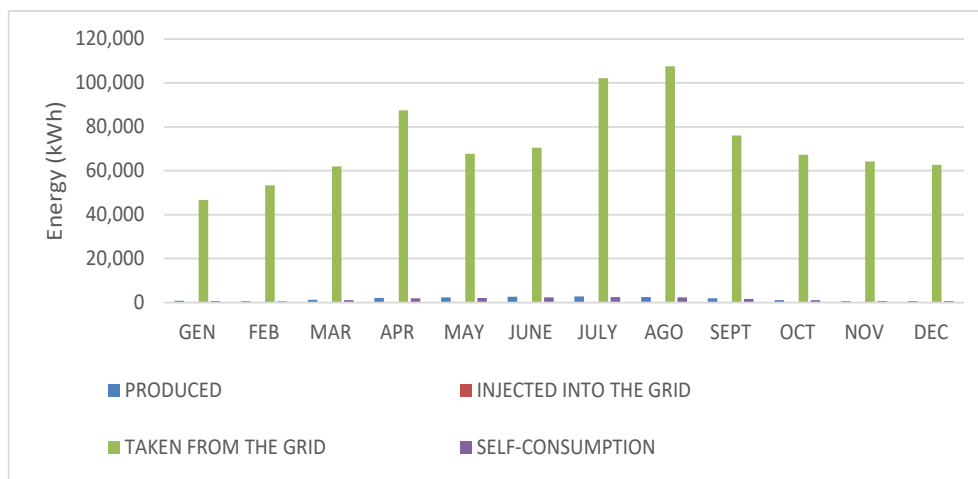


Figure 11. PV electricity production of the plant located at the water pumping station (in Campocavallo in 2018).

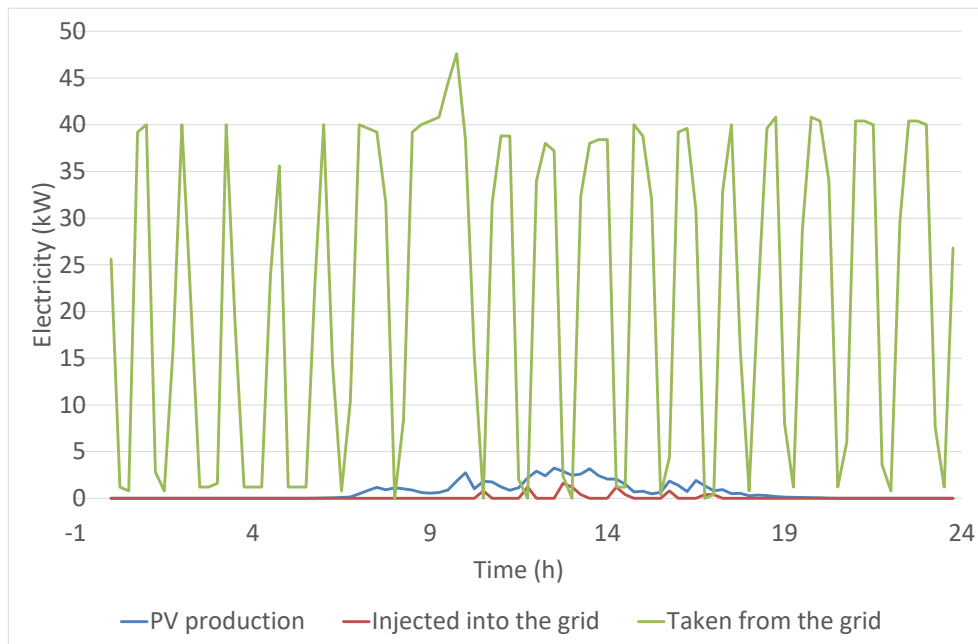


Figure 12. Electricity balance during a typical day.

3.2 New technologies to be installed for the DSM schemes

Given the above description of the demo site with its DSM instruments, the new technologies which have been selected to help to unlock the available flexibility or to increase it are described in the following sections.

3.2.1 Smart Controller

MUSE GRIDS project will develop a new multi-objective smart controller which will be tested in the Osimo and Oud-Heverlee demo sites. The multi-objective smart controller will be in charge of the energy dispatch in order to balance demand and generation and accomplish with the grid connection codes increasing the self-consumption within power-quality and comfort boundary conditions. Moreover, it will also use weather forecasts to implement an optimal control in a prefixed horizon taking into account demand and generation predictions.

The architecture and complete description of this Smart Controller will be presented in D1.3 of the project. In this section a brief description and considerations will be included in order to clarify the role of this controller in the DSM strategies. As D1.3 is still in progress some changes can be included in D1.3 with respect to the description included in this deliverable. Apart of the common structure some specific deployment issues related to both demo sites will be also detailed in this section and section 4.2.1.

The main objectives of the Multi-Objective Smart Controller are:

- Maximize primary energy saving and reduce LCOH/LCOE as optimization targets.
- Increase the self-consumption of the local energy community
- Increase energy efficiency and performance of each grid.
- Increase local energy district reliability: guarantee of supply reducing external contribution, increasing lifetime and reducing maintenance.

The Multi-Objective Smart Controller concept is shown in Figure 13.

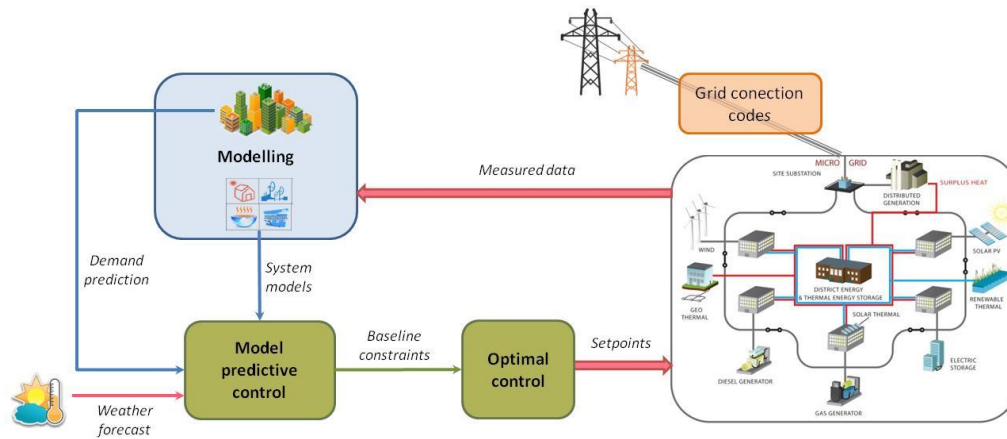


Figure 13. Multi-objective smart controller

The multiobjective smart controller will be key in the DSM strategy as it will manage storage capabilities and controllable loads in the grid. A predictive control strategy will be applied along a prediction horizon which makes it possible to plan the demand profile (e.g. shifting loads or charging/discharging batteries) according to expected users' needs, generated power and services/constraints required by the grid. As this DSM will be based on prediction models, it will be necessary to take into account the prediction errors and include in the smart controller an optimal control running at the lowest acquisition period of the grid that will adapt the planned DSM strategy to the real situation at any moment. As shown in the figure, actual set-points will take into account the baseline constraints that include long-term requirements and decisions.

The architecture of the smart controller is shown in Figure 14. Not every of the showed modules will be included in both demos. The architecture has been defined including criteria for an open, scalable and replicable control that can be deployed in new local energy communities and energy islands. Some of these modules can be deployed using different hardware or software in the different demos according to the restrictions of the already installed devices, plants or IT systems. The common architecture will guarantee that all these modules will be "interoperable", and that in the future different providers could include new improved versions of the modules.

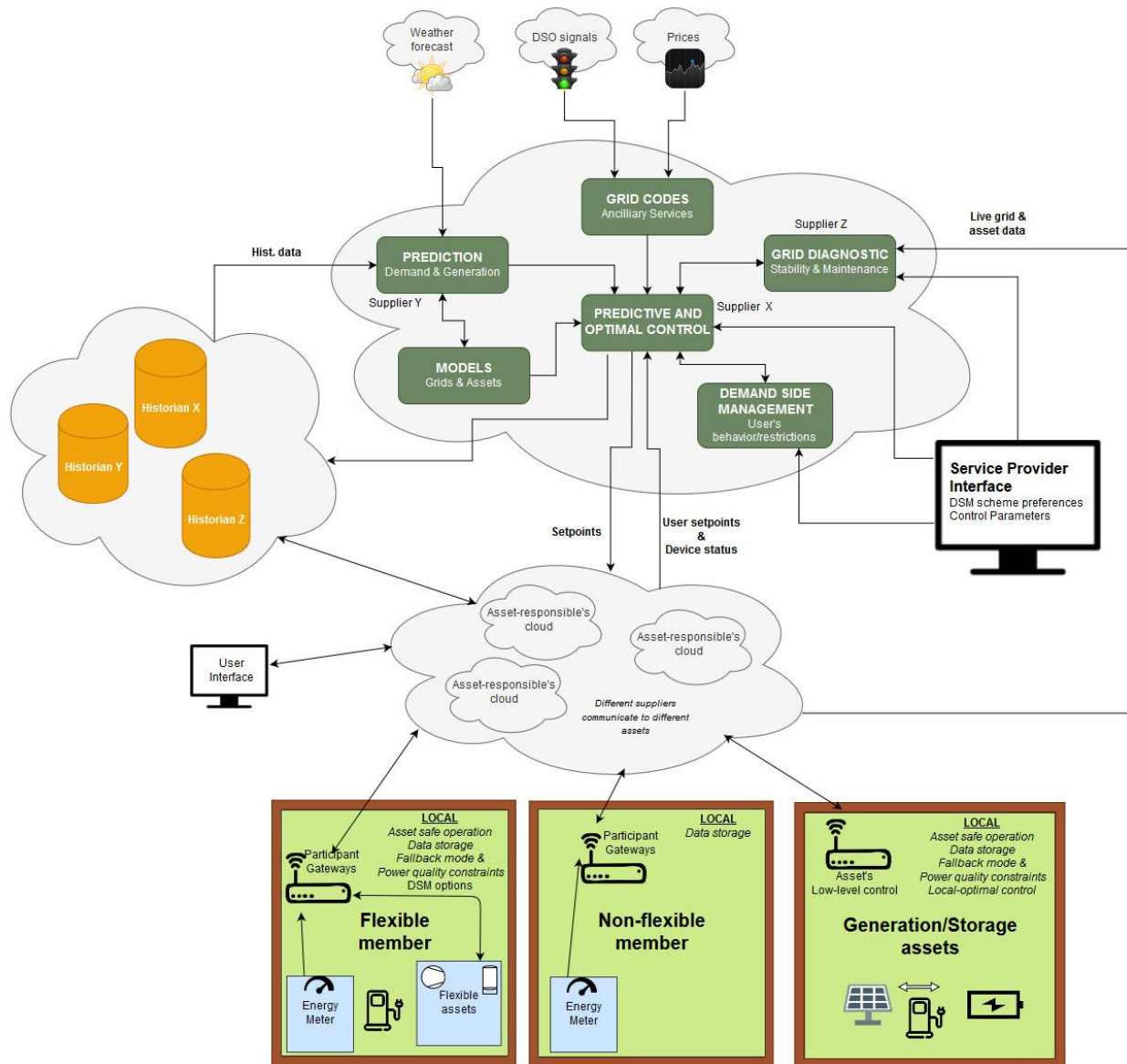


Figure 14. Smart controller architecture.

The main modules of the architecture are:

1. **Historian:** a digital area where data can be stored in well-defined structures. Each partner in the project will have their own historian, but the one of importance for the controller is the historian on the same *foundation* (a shared platform for different applications/modules) as the controller.
2. **Optimal and predictive control module:** application in charge of generate the set-points and orders for all the assets using the forecast, models and grid codes modules information. These set-points will fulfil the multiple objectives (functional and economic) and restrictions (characteristics of the different flexible assets) in short and long term.
3. **Modelling module:** there is a twofold objective for these models:
 - a. generation forecast according to weather forecast and plant operation mode
 - b. grid models for the optimization algorithm and model predictive approaches.
4. **Demand prediction module:** will be mainly based on historical consumption data and wheather forecast. The expected consumption is related to the time of day, day of the week, time of year (season), and official holidays

5. **Demand side management module:** will manage and communicate with industrial/public users whose demand can be easily shifted in time according to some restrictions and using storage/reserve systems (user's flexibility). It will also evaluate and take into account changes in users' behaviour in a medium-long time that could increase renewable share in the grid or self-consumption level according to new deployed actions and policies for user's engagement.
6. **Grid codes module:** definition of the grid connection codes and management of the provided services to the grid. These modes will be communicated to the control module as restrictions, generation availability or energy demand in order to accomplish with the grid codes.
7. **Grid diagnostic module:** an application which will monitor the grid and give an indication of the 'grid health' at each moment. The grid health will be used to determine the power quality constraints of the optimizer.
8. **User interface:** an application where the operator can command the demo site remotely. Control mode of all assets of the demo site can be changed and also the control of the whole plant. Probably at Local level a user interface will be also available. All data showed in the User Interface will come from the data acquisition system of the Local level.

Besides these modules, other elements can be included in the control architecture even though they are not part of the smart control itself. Three of these elements are:

- **Local Gateways:** hardware or software that will be in charge of the communication through industrial protocols (such as Modbus, ProfiBus, ProfiNet...) with the local devices. They will be part of the data acquisition system, will send the measurements from all devices of the plant to historian data base and will send the set points to the assets of the plant. They will be also in charge of deploy the fallback modes.
- **Low-Level Controls:** will manage the assets at local level taking into account the set-points received from the smart controller and the actual conditions of the plant. They can also implement advanced DSM strategies under the supervision and global set-points of the Smart Controller (eg: sharing available power among a group of EVs). Low-level control will have a key role to guarantee safety and security operation when connection is lost between local devices and smart control.
- **Weather forecast:** will be downloaded from the Internet and used as input for the energy dispatch. It will be sent to the Central Server to use it in the models.

Regarding Osimo demo the Smart Controller will manage the controlled assets treating them as a microgrid, and it will include the module for the energy exchange with the grid (Grid Codes module). Therefore, it will be prepared to accept setpoints and connection mode configurations from the TSO.

The Smart Controller will communicate with all assets of the micro grid using different communication protocols, and that communication will be used with the purpose of sending set-points and receiving alarms and measurements to feed the control.

Smart controller will command devices detailed in Section 3.1 and 3.2:

- Local and RES energy production systems (e.g. PV panels).
- Storage systems (e.g. thermal storage in the CHP plant, electric storage in the water pumping station).
- Interactions among different grids (cogeneration plant, electricity grid, natural gas grid).
- "Controllable" loads: e.g. EVs, electric heating systems, etc.

It must be able to communicate, using different protocols, with all assets of the demo project and it must also accomplish with the required time cycle that has been set to 15 minutes, as this is the acquisition rate of most of the available data for generation systems and users demand.

At this moment ASTEA is designing a new acquisition system that will be the basis for the historian module.

3.2.2 Electric heating technologies

GDHVI will provide Smart Electric Thermal Storage (SETS) systems for both the Italian and Belgian demonstration sites within the Muse Grids project in order to increase the flexibility related with heating/cooling systems and DHW production. In Osimo 4 SETS space heaters and 2 water heaters will be installed.

Technical specifications

Smart electric thermal storage (SETS) is based on the existing technology of traditional night storage heaters, designed to reduce the large differences in peak and off-peak electricity demand. Traditional night storage heaters have an insulated thermal core that stores heated during the night (to avail of more abundant low-cost energy), and then releases it during the day (when demand and prices are higher). The SETS system is more flexible in that it allows the core to be charged at any time, to suit electricity grid conditions, as well as offering end-users more control over the release of this heat and potential costs savings with efficiency gains compared to traditional night storage heaters. SETS concept is illustrated in Figure 15. In Figure 16 the available SETS sizes and technical specifications are reported.

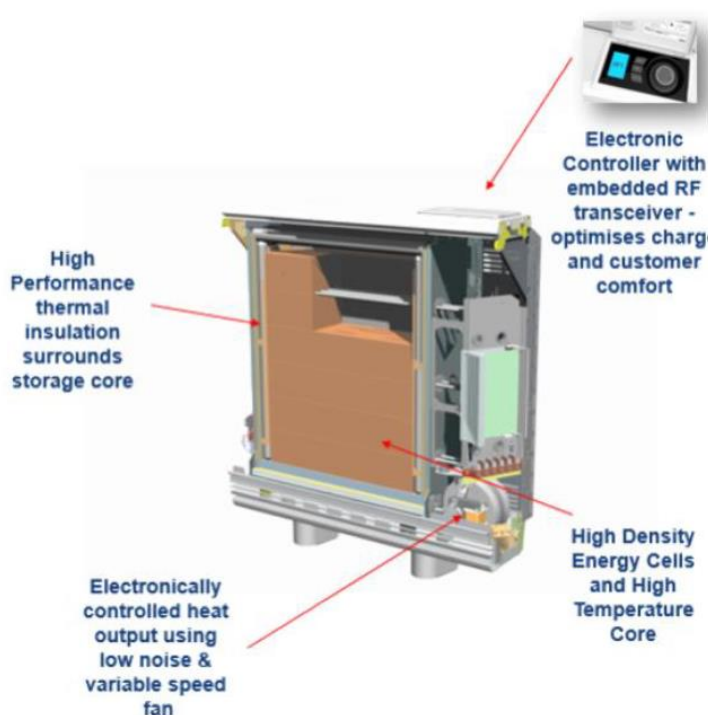


Figure 15.SETS concept illustration

Model No.	Input Rating +5%/-10%	Output Rating	Boost Mode Rating	Maximum Storage Capacity (Wh)
QM050	1020W	500W	340W	7140
QM070	1560W	700W	520W	10920
QM100	2220W	1000W	740W	15540
QM125	2760W	1250W	920W	19320
QM150	3300W	1500W	1100W	23100

Figure 16. SETS technical specifications.

As far as the DHW production is concerned, different sizes of the electric water heater are available, as reported in Figure 15. Volumes for water heating cylinders range from 125 L to 300 L (see Figure 17). The tank temperature set-point varies between 40°C to 65°C.

Model Name/Item Code	Cylinder Capacity	Element 1 & 2	Maximum Capacity (kwh)
QWcd 125 - 580 (IoT)/081858	125L	3 Kw	7.927
QWcd 135 - 480 (IoT)/081865	135L	3 Kw	8.561
QWcd 150 - 580 (IoT)/081872	150L	3 Kw	9.512
QWcd 180 - 480 (IoT)/081889	180L	3 Kw	11.415
QWcd 210 - 580 (IoT)/081896	210L	3 Kw	13.317
QWcd 250 - 580 (IoT)/081902	250L	3 Kw	15.854
QWcd 300 - 580 (IoT)/081919	300L	3 Kw	19.024

Figure 17. Water heating cylinders technical specifications.

Control strategies

The SETS space heating device has an on-board control system which allows the thermostat to be set within the range of 7-30°C and is programmable. The present controller has the following modes (Figure 18):

Mode		Timer profile	Setpoint
Timer	User Timer	Upto 4 periods per day	User Adjustable 7-30°C
	Home All Day	Upto 4 periods per day	User Adjustable 7-30°C
	Out all Day	Upto 4 periods per day	User Adjustable 7-30°C
	Away	Continuous heating mode during Away period	User Adjustable 7-18°C
Frost Protect		Continuous heating mode	Fixed 7°C
Setback		Continuous heating mode during Heating Off	User Adjustable 7-18°C
Boost		Timed mode	User Adjustable 7-30°C
Adaptive start		Automatically adjusts the comfort period start time	User selectable
Open Window Detect		Switches heater off if open window detected.	n/a

Figure 18. SETS controlling modes.

The SETS devices use sophisticated charging control routines to calculate and optimise the energy required to be stored to deliver the customers comfort requirements within the constraints of their available off-peak tariff. The devices calculate the charge runtimes based on multiple inputs including, for example: seasonal band (room rate of change), heat demand, number of heating hours, room setpoint, standing losses, adaptive functions and residual energy.

The SETS space and water heaters are compatible with the Dimplex Control IoT platform. The diagram below (Figure 19) shows how the appliances communicate with the cloud via the Dimplex Hub using 868Mhz RF (appliance to gateway) and wi-fi / ethernet (gateway to cloud).

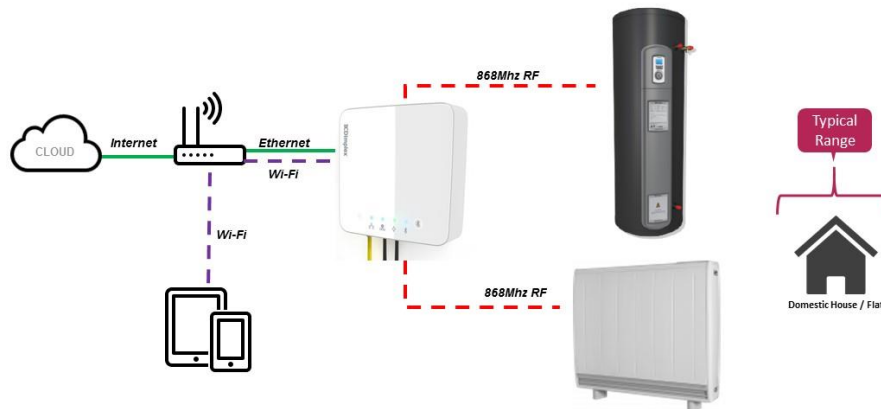


Figure 19. Appliances communication mode.

Each GDHVI SETS device can be controlled through connection with the Dimplex IoT platform, which enables the provisioning of Dimplex products along with the transmission, storage and retrieval of telemetry information. It also enables consumers to control Dimplex products remotely (via the Dimplex Control app) and provides external access to other businesses (e.g. energy supplier, aggregators etc.) who have an interest in controlling the charge profiles of suitable products.

Remote configuration of charging profiles and charging modes is done through accessing the Dimplex Control API (application programming interface). The DSM Control API is a fully managed and monitored system.

Applicability in the DSM schemes

These devices can be easily used to exploit the flexibility related to heating demand in buildings. They can communicate with an external control architecture and be controlled through proper external signals: the smart controller can communicate the schedule for the device and by-pass the on-board controller in order to achieve the DSM objectives.

An aspect to be taken into account is that switching any electrical load can lead to unwanted EMC (Electromagnetic compatibility) issues with other electronic equipment. It is therefore not best practise to rapidly switch electrical loads. Based on this it is recommended that the time between switching events is limited to 15 minutes. So if an appliance is switched on it should stay on for a minimum of 15 minutes and if an appliance is switched off it should stay off for a minimum of 15 minutes.

Furthermore, the Quantum hot water cylinder can also be activated by the external DSM controller, however the exception to this is the hygiene function, the purpose of which is to stop the growth of legionella bacteria in the cylinder. This will be completed by the cylinder regardless of DSM control, and involves heating the water in the cylinder to 65°C, this should not be interrupted.

3.2.3 V2G and V2B technologies

In the Osimo DEMO site 2 charging stations will be installed:

1. The first one has AC (alternating current) output through both the type 2 plugs that are rated for a maximum power of 22 kW corresponding to a current of 32 A and a voltage of 400 V;
2. The second one has DC (direct current) output through the EU standard connector Combo 2 with the maximum power of 50 kW corresponding to a current of 125 A_{DC} and a voltage of 200 - 500 V_{DC}.

Charging stations' technical description and control strategies are described in detail below.

Technical specifications

Charging stations or EVSE (electric vehicle supply equipment) (Figure 20) are usually in the form of galvanized steel pillars connected directly to an electrical distribution panel. Charging stations usually have one or more charging connectors/plugs used to connect to the EVs' charging socket to charge their battery.

Moreover, EVSEs can be equipped with additional components, such as: the EVSE controller (which controls the low-level algorithms of the charging session), the HLC (high level communication module that allows the communication with the back end), lights that indicate if the EV is connected and charging, a button for starting or stopping the charging process, an energy meter, an electronic payment system, a card-controlled access system, Internet access, etc.



Figure 20. Charging devices.

Apart from the common components listed above, charging stations can be classified in two different macro-categories based on the output current of the stations:

- Alternating Current (AC);
- Direct Current (DC).

The key differentiator between charging stations with different current outputs is the presence of the power modules that convert the current (hence the voltage) from AC to DC.

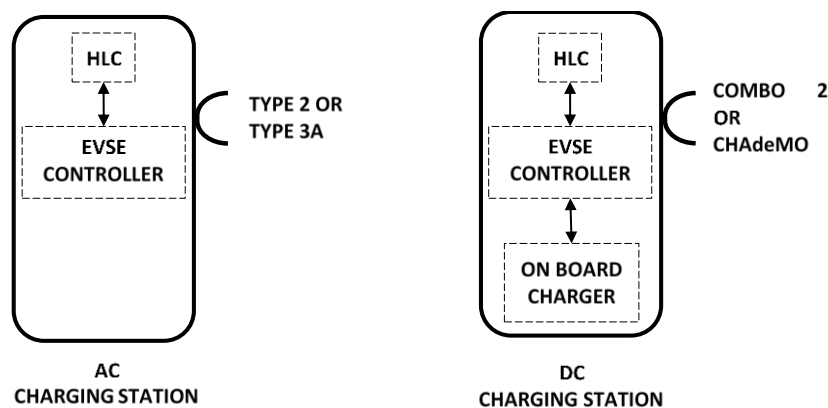


Figure 21. AC and DC charging stations

The charging infrastructures use different charging modes defined in the standard IEC 61851-1 (The Electric vehicle conductive charging system - Part 1: General requirement). The charging modes vary primarily in the charging power and the security level. The European solution for charging in public are described in the AFI-directive (2014/94/EU). Those charging modes relevant for the project are briefly described hereafter, namely charging mode 3 and 4.

Charging mode 3. The vehicle is connected to the supply network in AC (Alternating Current) using the EU standard connector Type 2 or 3A (IEC 62196) that has a pilot control circuit to check the continuity during the charging session, the protection conductor between the vehicle and the network. The control circuit is necessary to ensure the correct functioning of the protections against indirect contacts, preventing the discharge of dangerous voltages and currents on unaware people through the accidental contact of the metallic body of the charging station or the vehicle.

The circuit of control also provides the communication between the station and the vehicle (ISO 15118), through the PWM circuit, and the identification of the cable size (Resistor Coding).

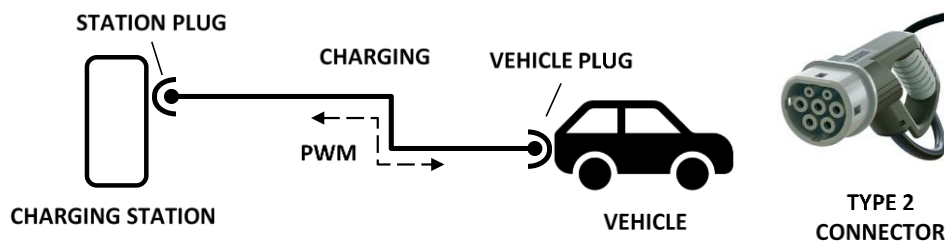


Figure 22. Charging mode 3

Charging mode 4. Charging station is connected directly to the vehicle through a connector that follows the EU standard connector Combo 2 or the Japanese standard CHAdeMO (both described in the standard IEC 62196).

The Combo 2 connectors are developments of the Type 1 and Type 2 connectors. Indeed, they have two additional direct current (DC) contacts to allow high-power DC fast charging (up to 350 kW).

The charging station converts the AC voltage coming from the distribution panel to a DC voltage through an on-board charger (IEC 61851-23 and 61851-24) that allows to bypass the off-board charger on the vehicle and reach higher voltages, currents and thus power.

Moreover, the communication between the vehicles and the charging station is managed through the standards DIN 70122 and ISO 15118.

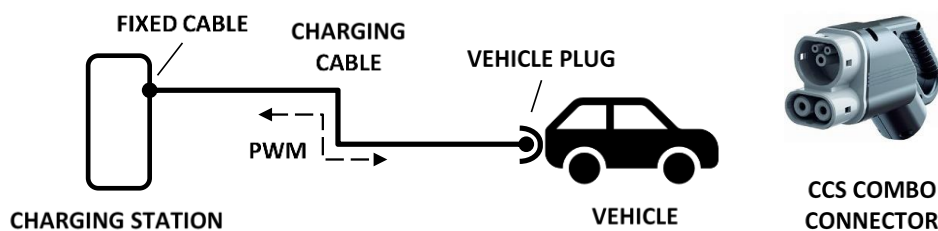


Figure 23. Charging mode 4

Control strategies

Charging stations can charge the vehicles batteries safely and fully without any control from a separate control system. However, to achieve a higher level of control, the charging stations can be connected to the IT system of the Charge Point Operator (also called CPO back-end) typically using GSM technology. The communication between the back-end and the charging stations is guaranteed by the HLC (high level communication module) which uses the “de facto” standard communication protocol Open Charge Point Protocol (OCPP) which is currently at the version 1.5.

As of today, the communication between the EVSE and the back-end ensures the continuous monitoring and the remote control of the charging station.

In addition to the basic control of the EVSE, the flexibility of the IT system opens the possibility to apply complex control strategies to the charging session and turn the vehicles connected to the grid into a dynamic energy storage.

The smart control of the energy flow is also called **Power Management System (PMS)** and it has 3 steps of development:

- Level 1: real-time control of the charging session as if the vehicles are programmable consumers based on the constraints of the point of delivery (POD). The objective of the first level of the PMS is to automatically meet the constraints of the local electric grid and at the same time optimize the power delivery to the vehicles at the maximum capacity of the grid.
- Level 2: the PMS optimizes the charging session taking into consideration all the electrical system in which the EVSE is installed. Hence, the charging station is a key component of the so-called Smart Energy Building and the PMS increases the overall stability and quality of the grid. The benefits of this level of automation are diverse: making use of all the power capacity of the POD of the building and minimizing the power increase that would be necessary to supply the charging station; coordinating with the building energy loads to flatten the power usage to improve the stability and the energy consumption; increasing the self-consumption of the renewables energies, if present.
- Level 3: advanced strategies as time-scheduling, energy cost reduction and bi-directional energy flow. The PMS uses user preferences to charge and discharge the vehicle based on different priorities. For example, hypothetically, if the energy cost is lower during the night than in the daytime, the PMS can automatically start the charging process when the user pays less. In addition, the PMS can exploit the bidirectionality of the on-board chargers (the power converters inside the charging station) in a system called Vehicle to Building (V2B) or called Vehicle to Grid (V2G). Especially V2B and V2G technologies are enhancements of the PMS level 2 because the effects and the objectives are similar but they are on a larger scale. Since the technology allows not only to stop the charge but also to use the energy and power of the vehicle's battery, the capability of stabilizing the grid, such as a peak shaving, and the resulting economic value are higher.

As a result of these different strategies, the PMS will always adhere to the grid constraints and follow the defined optimization driver (e.g. energy price or FV production) that the user prefers in order to adjust the electric vehicle charging process and use the energy when it is more convenient.

Considering the above, however, the vehicles are not a static storage, instead they always move. Then, the very nature of the vehicles sets several limitations that can be restricted if the following pieces of information are known:

- The schedule of the vehicles usage (e.g. work shifts, etc.);
- The guarantee of the daily trips of the vehicles.

Applicability to DSM schemes

The PMS use a large set of input data, some of which will be offline and some will be real-time, to compute the optimal charging strategy according to the constraint and the defined priorities.

The offline data are declared at the setup of the charging infrastructure and they are specified directly in the CPO back-end which feeds data to the PMS. These data can be:

- The constraints of the grid (maximum power in [kW]);
- The constraints of the vehicle and the charging station (maximum and minimum current of the charging session in [A]);
- The physical description of the electrical system (how many phases, on which phase is installed the charging station);
- The list of priorities for the optimization (energy consumption or cost).

On the other hand, real-time data are made available to the PMS from different sources. Firstly, the EVSE sends the data about the charging session to the back-end which sends them to the PMS, finally the DSM or other sources give the data related to the grid or the vehicles status. Real-time data are:

- Available power at the point of delivery;

- FV production;
- Building overall consumption;
- Building overall withdraw from the grid;
- Power consumption of all the plugs/vehicles;
- State of the battery (charging level and energy needed to complete the charging);
- Desiderata state of the battery;
- Logistic scheduling update.

Service Providers represent the actors who can enable the abovementioned interaction between the grid and the charging stations. The result of the integration is a creation of a diffused network of storage systems and all the benefits that result from it.

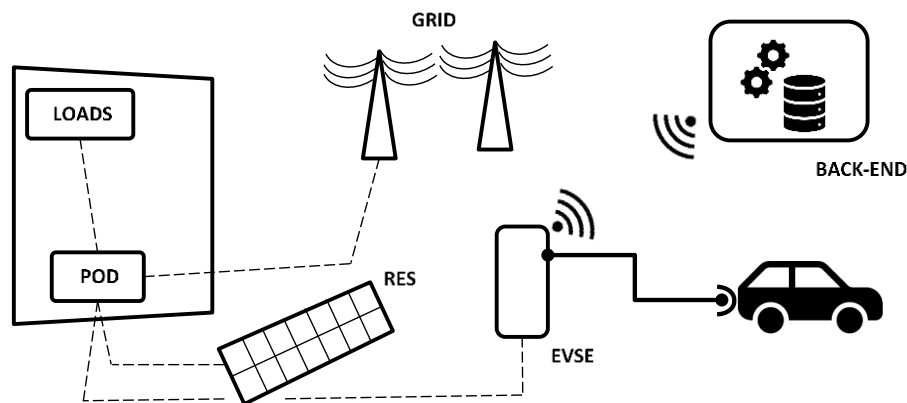


Figure 24. Power management system

3.2.4 Thermal energy storage

A thermal energy storage (TES) will be installed in the CHP plant. The CHP has the potential to satisfy more of the district heat load, but currently large gas boilers are being called on due to lack of thermal energy reserve. The Osimo demo site has a clear requirement for a thermal store. However, factors like the initial cost and the difficult positioning/placing requirements of the thermal store have negatively affected this additional system integration. On the other hand, among the factors that instead make the integration worthwhile is efficiency increase.

Technical specifications

The vessel has been designed to be as tall as possible to optimise stratification. Input/output diffusers have been designed to maintain optimal thermal layering. Other factors to influence the design include thermal efficiency. The tank must be very efficient and not lose/waste heat energy through its outer surface. Extremely good product has been selected that has favourable fire resistant properties and also heat retention capabilities.

Much of the control required will be as a result of clever design. Utilising baffle plates and diffusers for layering control will be taken care of. There are physical constraints given the area required to house a thermal store. This has been optimised by utilising below ground space in order to maximise store volume.

Thermal store specification:

- Volume approx 80,000 liters
- Diameter 3200mm
- Height 12000mm
- Body Steel type 6MM S275
- Dished ends steel 10mm S235
- Insulation specification: 100mm high density polyurethane U-Value 0.22W/m2K

- In Figure 25 the preliminary schematics of the vessel integration into the plant can be seen.



The thermal storage is used as an energy reservoir which provides flexibility to the CHP-DH operation. It allows different control strategies of the CHP plant in order to accomplish the DSM objectives. A preliminary assessment has determined that the TES can make the CHP working more hours during mid-season or even summer (e.g. in May the operating hours could be increased of about 140 hours charging the storage during periods when the DHN demand is low). Given the high volume involved it does not perform a fast response, then its scheduling must be preferably determined in advance with predictive algorithms if specific objectives want to be accomplished within a given time.

36

Table 3. Measured data in Osimo demo site.

DHN - CHP Power Plant			
Description	UNIT	data acquisition mode	Time step
Lower heating of natural gas	kWh/Sm ³	manual ¹	monthly
Total gas consumption	Sm ³	manual	monthly
Boilers gas consumption	Sm ³	manual	monthly
CHP gas consumption	Sm ³	real-time ²	15 min
Total thermal energy ³ supplied to the DHN	kWh	real-time	15 min
Boilers thermal energy production	kWh	real-time	15 min
CHP thermal energy production	kWh	real-time	15 min
CHP electric energy production	kWh	real-time	15 min
PV Plant production	kWh	manual	15 min
Electric energy delivered	kWh	manual	15 min
Electric energy used in the plant	kWh	manual	15 min
CHP auxiliaries electricity demand	kWh	real-time	15 min
Water pumping station			
Description	UNIT	data acquisition mode	Time step (min)
PV Plant	kWh	manual	15
Electric energy delivered	kWh	manual	15
Electric energy used in the plant	kWh	manual	15
Astea Headquarter - December 2018			
Description	UNIT	data acquisition mode	Time step (min)
PV Plant	kWh	manual	15
PV electric energy delivered	kWh	manual	15
PV electric energy used in the plant	kWh	manual	15
Building electricity demand	kWh	manual	60
Building natural gas demand	kWh	manual	60

¹“manual” means that it is necessary to download manually data from the considered devices acquisition platform

²“real-time” means an automatic update of the collected data

³The thermal energy is measured indirectly through flow rates and temperatures measures.

In Figure 26 a detailed layout of the CHP plant and available instruments is provided.

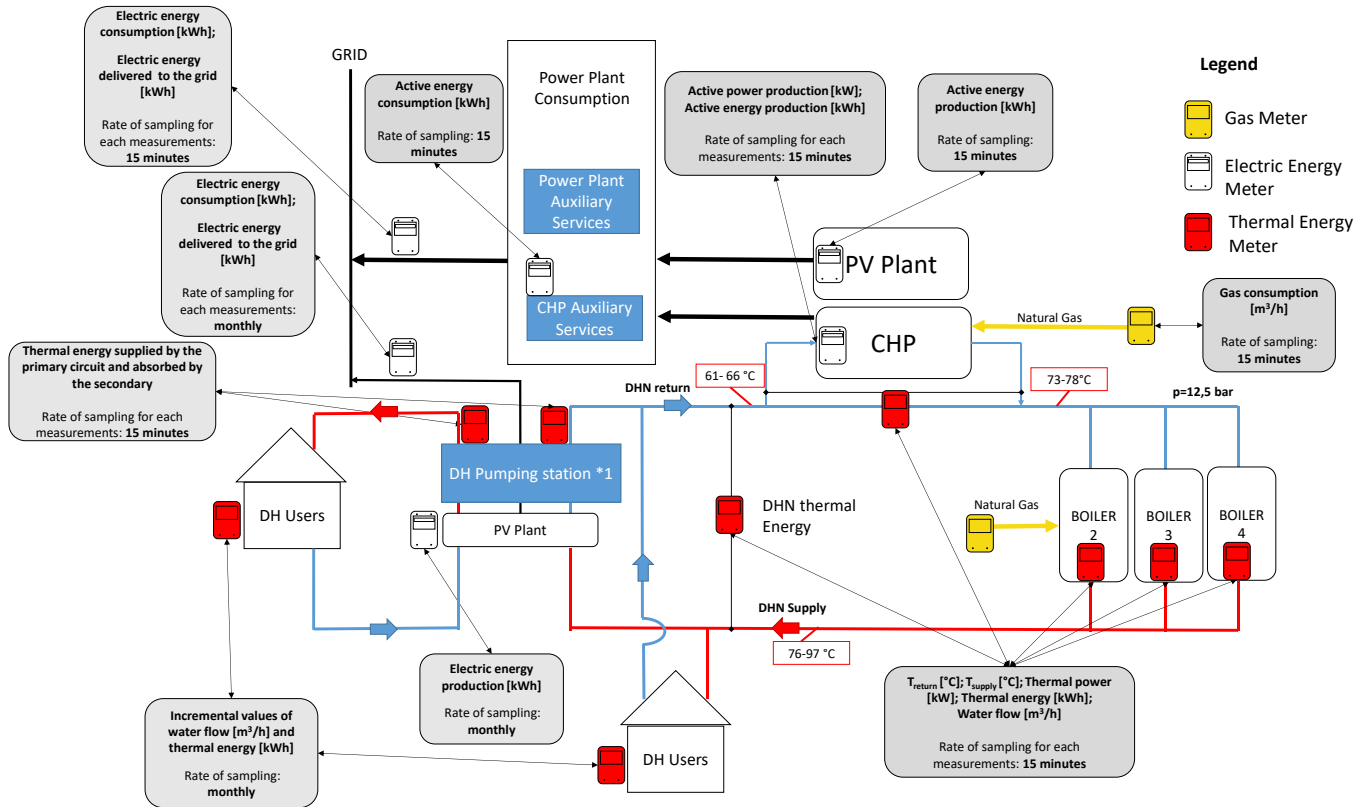


Figure 26. Layout of measurement systems in the CHP-DH plant.

As already discussed in Section 3.1, the analysis of the data recorded from the above instruments allow the assessment of the CHP plant performance and PV electricity production and present self-consumption rate. The granularity of the available measurements and their accuracy is considered satisfactory to obtain useful hints to design the DSM schemes and to enable the necessary control. Only more detailed data would be necessary at building level, in order to know energy use divided by source. Already from a first evaluation of available data, possible improvements of the system energy management can be studied and proposed.

In addition to these data, the overall electric balance for Osimo electricity grid (electricity injected into or taken from the national grid) is known with a time step of 15 min. Looking at these measured values it was possible to highlight the high PV electricity production from all the PV panels installed in Osimo, which is much higher than the demand during weekends and holiday periods, especially in summer. This fact causes a huge amount of electricity injected into the national grid, in contrast with the high electricity taken from the grid during weekdays (maximum power around 30 MW). The monthly PV production from all the PV panels installed in Osimo is reported in Table 4.

Table 4. Total PV production in Osimo (2018).

Month	Production [MWh]
Jan	2,022.40
Feb	1,763.53
Mar	2,783.41
Apr	3,529.97
May	3,728.46
June	3,949.65
July	3,920.22
Aug	3,528.86
Sep	3,103.17
Oct	2,281.80
Nov	1,972.74
Dec	2,021.18
Total	34,605.38

In Figure 27 the electricity taken from the grid in typical weekdays in the different seasons is shown. The load curve has a typical shape with two similar peak power demands (apart in Spring where the noon peak is lower than the evening peak). The peak value is around 30 MW.

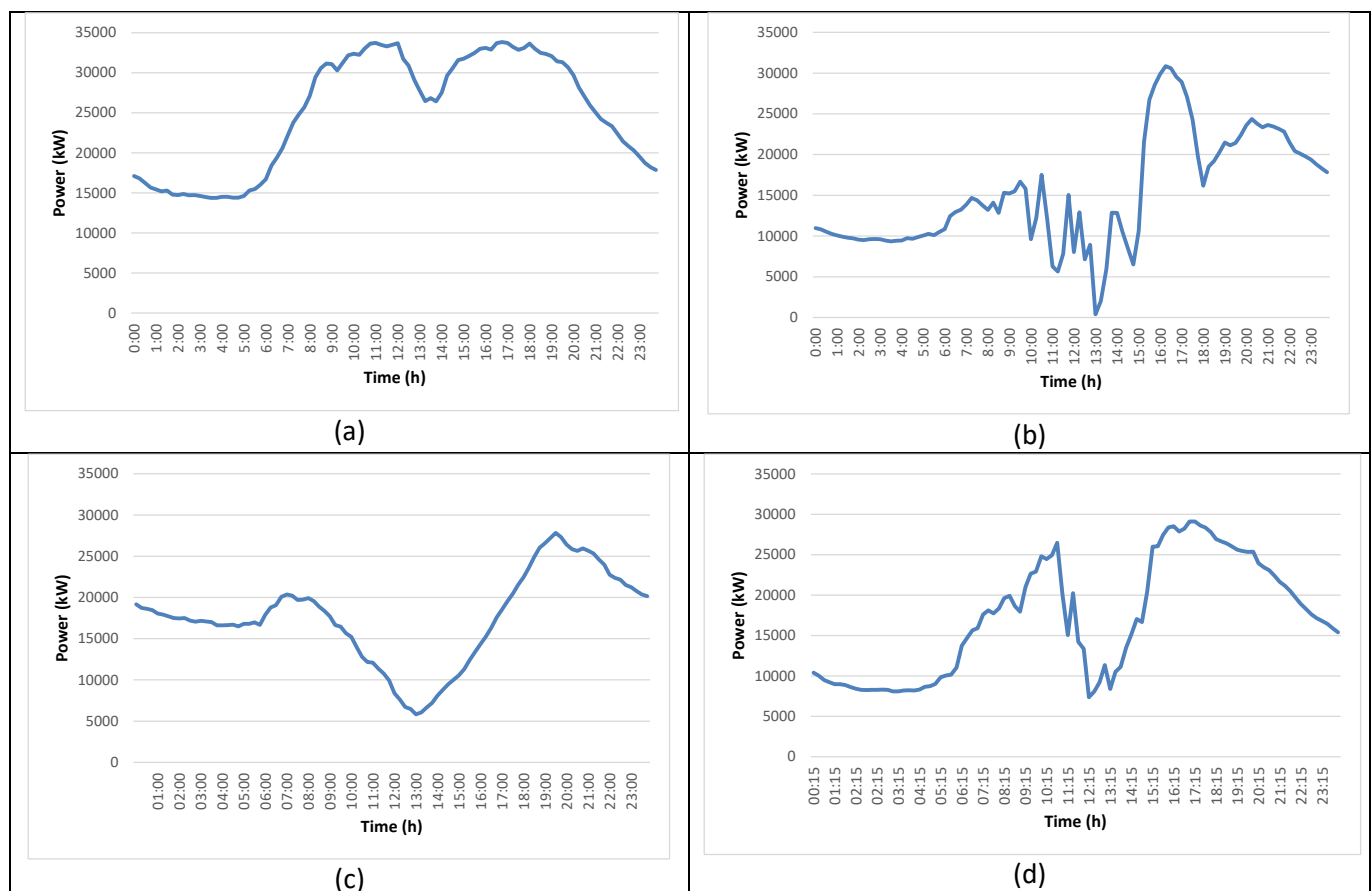


Figure 27. Electricity taken from the grid in a (a) winter, (b) spring, (c) summer and (d) autumn day (2018).

In Figure 28 PV electricity injected into the grid in representative days in the four seasons is represented: the occurrences are always during weekends and summer holidays and the most critical periods are both mid-season and summer (in May a peak injection power of 14 MW is observed).

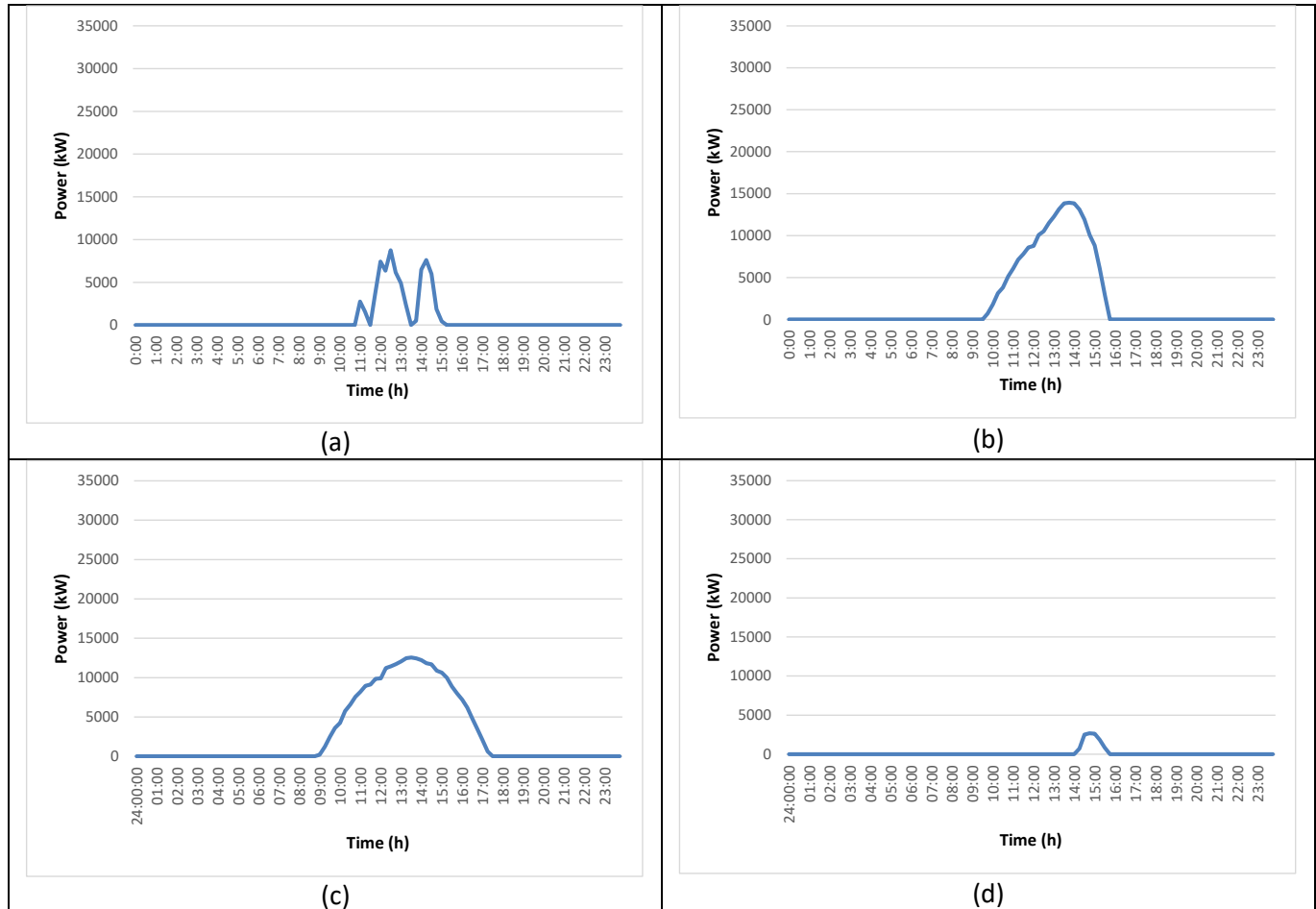


Figure 28. PV electricity injected into the grid in a (a) winter, (b) spring, (c) summer and (d) autumn day (2018).

3.4 DSM schemes and objectives

The analysis of the present situation in Osimo has highlighted that, due to the high penetration of renewable energy generation (mostly PV), the municipal microgrid witnesses a huge variance in the electric power exchange with the national grid throughout the year, swinging from 30 MW of peak absorption, when the renewable generation is not sufficient to cover the local energy demand, down to 15 MW of peak injection towards the national grid, when the local generation exceeds the total loads (mainly during summer weekends). Furthermore, there are some PV panels installed locally to provide electricity to specific installations, such as the water pumping station in Campocavallo, which do not use completely the PV electricity production because demand and supply are not simultaneous.

Thus the DSM schemes which have been selected are aimed at reducing the power injection into the grid and at optimizing the PV self-consumption by means of **load shifting strategies**. Furthermore, peak electricity demand towards the national grid can be clipped by means of proper **peak shaving strategies**.

Another critical issue highlighted by the analysis of the current situation concerns the **optimal management of multi energy vector systems**, such as the CHP plant, where natural gas and electricity are both used and produced by the different generators (i.e. cogenerative gas engine, gas boilers and heat pump) and their operation has to be optimized in order to minimize primary energy use. This aspect is observed also in buildings, where the production of thermal heating and cooling loads involves different carriers (i.e. natural gas and electricity).

DSM schemes could be beneficial also to solve power quality issues, however there are not electricity network branches with such problems close to the selected demo activities.

With more detail, the DSM schemes for each flexibility provider specified previously are discussed in the followings. They include different possible interventions, such as implementation of **energy efficient devices, use of energy storage systems and optimal control**.

3.4.1 The CHP-DH plant

The energy flexibility of the CHP plant comes mainly from the operational strategy of the plant itself, i.e. by varying the ratio electricity/thermal energy produced, and it can be implemented in several ways. Some possible strategies are discussed below.

- The CHP plant can be considered as a final user within the microgrid of Osimo and its electricity production varied according to the overall grid needs. For example, it could be completely switched off during the periods of high electricity injection into the national grid. This action would be beneficial especially during winter when the CHP electricity production is of the same order of magnitude of PV over production.
- Optimal management of the gas engine cogeneration system and gas boilers in order to reduce primary energy use and maximise the flexibility provided to the grid. Indeed, at present the CHP management is based only on the current economic incentives policy and it does not take into account the energy resources deployment. Possible actions to be implemented include:
 - Reduction of gas boilers use where possible by incrementing the share of the gas engine working hours e.g. during mid-season when it works at part load.
 - Use of the **thermal energy storage (provided by GALU)** to increase the energy efficiency of the gas engine, avoiding continuous switching on/off cycles, even when the load is reduced as in summer, so that this prime mover can be used instead of conventional boilers for more hours.
 - Act on the DH supply water temperature set-points in order to maintain the temperature in the pipelines as low as possible and avoid energy waste.
 - Employ the heat pump to produce thermal energy when an excess of electricity is available.
 - Involve the DH final users so to modify their inside air temperature set-points and adjust the demand to the optimized CHP thermal energy production. Consider the implementation of local electrical “boosters” to supply heat in case of surplus electricity availability.

3.4.2 Energy flexible buildings

The considered buildings provide flexibility by means of the thermal storage of building envelope and by the storage capacity of the innovative **GDHVI electric heaters**. Moreover, the EVs can be used to store or provide electric energy through the **DUFERCO charging station** when necessary.

Figure 29 represents a schematic with the DSM devices included in Astea’s headquarters.

In Table 5 the specifications of the new devices installed is reported.

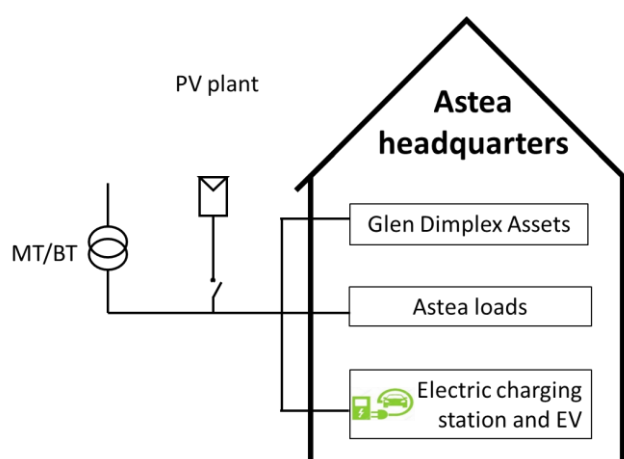


Figure 29. Astea's headquarters DSM technologies.

Table 5. New DSM devices to be installed in Osimo demo.

Location	Appliance	Model	Energy performance
Astea HQ – leisure area	SETS space heater	2 x QM100	Input rating: 2220 W Storage capacity: 15540 Wh
Astea HQ – changing room	SETS water heater	1 x QWCd300-580 IOT	Volume: 300 l Input electric power: 3kW Energy storage capacity: 19000 kWh
Astea HQ	EV charging station	AC output - type 2 plug DC output - EU standard connector Combo 2	Maximum power of 22 kW corresponding to a current of 32 A and a voltage of 400 V; Maximum power of 50 kW corresponding to a current of 125 A _{DC} and a voltage of 200 - 500 V _{DC}
Astea CHP plant – changing room	SETS space heater	1 x QM070	Input rating: 1560 W Storage capacity: 10920 Wh
Astea CHP plant – control room	SETS space heater	1 x QM150	Input rating: 3300 W Storage capacity: 23100 Wh
Astea CHP plant – plant room	SETS water heater	1 x QWCd300-580 IOT	Volume: 300 l Input electric power: 3000 W Energy storage capacity: 19000 Wh

The DSM schemes objectives address the reduction of peak electricity demand and injection from and into the national grid. The optimal management of the above mentioned flexible devices will be implemented in order to demonstrate the load shifting and peak shaving potential of tertiary buildings. Results can be scaled up at city level in order to quantify their impact on the overall microgrid performance. For example, the SETS space heater installed in Astea's headquarters with an electric power of about 2 kW could provide a reserve power of 2 MW if installed in 1000 different buildings in Osimo and, given its storage capacity, it allows several hours of load shifting.

3.4.3 Water pumping station

The water pumping station represents the connection point between the electricity grid and the water grid. Here the DSM purpose is to increase the locally installed PV plant self-consumption. At present the self-consumption share is about 90%, the electricity has to be injected into the national grid when there is a mismatch between demand and production.

A new pumping control strategy will be studied in order to increase the electricity demand when more renewable electricity is available. Furthermore, an electric energy storage with a capacity of 30 kWh will be installed to store

the surplus PV production. Given the maximum power injected into the grid (see Figure 10), such storage provides several hours of storage capacity.

This installation will be used to demonstrate the use of energy storage systems (namely **electric storage**) to maximise the renewable energy sources (RES) exploitation (i.e. PV electricity production) through load shifting.

3.5 User engagement strategies

Main actor in DSM schemes application in Osimo will be Astea, as utility. Their assets will be used to implement the above mentioned DSM strategies.

People involved in Osimo demo will be both the DH users and people working into Astea's office buildings.

In particular, regarding the DH users, the idea is to involve them by asking a modification of their indoor temperature set-points. It is under evaluation the possibility of providing them an app from which receiving advices on how to use the heating system. They will not have expenses, but rewards have still to be defined at this stage. Whereas in Astea's buildings there is a central heating/cooling system. Therefore, a real interaction with the users, i.e. people working in the offices, is not mandatory to implement the DSM strategy. However, they have to be aware about the projects and its objectives. Even here temperature set-points could be changed (always in the comfort range).

Furthermore, given that private PV panels contribute considerably to the electric demand production in Osimo and given the issues highlighted in the previous analysis about PV electricity injection into the grid, the PV panels private owners could be involved in DR programs by making them aware about the grid needs of load shifting. A similar approach proposed for the DH users could be followed.

In the following some actions to be implemented during the project are described in detail.

3.5.1 Astea's workers

Motivational actions (and social research)

- Motivational pills: through Astea's communication channels (corporate website, newsletters, etc.) references to the difficulty of RES incorporation that Muse Grids wants to solve could be disseminated, preferably through examples.
- If those media resources do not exist, a digital newsletter could be developed to be distributed among the Astea staff approximately every two months.
- Survey on energy habits: aimed at knowing the energy habits of Astea workers and also to assess their opinion on current energy comfort. It should also include questions addressed to learn about the degree of knowledge between individual energy consumption and climate change, and the vision of their personal role in the energy transition.

Communication actions

- Through Astea's communication channels (corporate website, newsletters, etc.) and/or by creating a digital newsletter to distribute among Astea's staff, with sequenced content such as:
 - Make objectives of the MUSE GRIDS project known, as well as the benefits it seeks to achieve.
 - Report about the energy consumption in Astea (if such data is available) and specifically that related to the heat network.
 - Introduce general knowledge about energy flexible technologies.
 - Energy habits: give back the results of the survey.
- Press release: to the local media, announcing the incorporation of Astea to the MUSE GRIDS project.

Participatory actions

- Start-up of an internal working group for energy improvement of the Astea building: formed by people motivated to do so, it will serve to put into context the work of MUSE GRIDS and facilitate the implementation of the proposed measures. A working group facilitated by expert personnel would meet periodically to:
 - Analyze the energy performance of the building (within the boundaries of available resources),
 - Make proposals for energy improvement in the building.
 - Evaluate and integrate the proposals of MUSE GRIDS.
 - Propose means of communication for the MUSE GRIDS proposals to the Astea staff.

3.5.2 DH users and PV panels owners

Motivation actions (and social research)

- Letter: sent to DH clients, preferably in a shipment separated from the invoice, with the aim of publicizing the project, generate interest in participating in it and make visible the opportunities (environmental improvement, innovation, example for other places, ...) that it generates.
- Survey: telematics or by telephone, addressed to know the degree of satisfaction with the DH service, the usability of the app, etc.
- Invoice as a communication asset. In a first stage, with messages and contents linked to the risks associated with climate change, the problems of integration of renewables, the interest of the Energetic Communities, etc.

Communication actions

- App: that allows the user to interact with his heating system. Actions yet to be defined.
- Socialization of results: associated with the app, it would be desirable to make it possible for a user to compare his or her behaviour in comparison with the rest ("80% of users save more than you"), to stimulate efficiency.
- Public counter (of avoided CO₂, for example): that allows to quantify the results of the project and to share them.
- Presentation party: Trying to work the coherence between content and continent (fed with renewable energies, with reusable materials and locally produced products, etc.), this party would be a playful event designed to present the app and introduce and stimulate its use. Activities that promote the bonding between the participants in a carefree environment will be sought.
- Use of the invoice as a communication element: In this stage, invoice could be used to publicize the characteristics of the system applied by Muse Grids, the changes that the user (and especially those that are NOT going to affect him or her directly) may have and its environmental benefits.

Participatory actions

- Workshops for schoolchildren: using schoolchildren as vectors of communication with their parents, workshops aimed at incorporating energy efficiency in the home could be designed.
- Exchange of ideas for improvement: through the app, a system that allows users to exchange the improvements they apply could be deployed. Applied measures of the users with best rating could be disseminated.

4 DSM schemes in Oud-Heverlee

4.1 Existing technologies to unlock flexibility

4.1.1 Mapping of assets in the neighbourhood

Data collection for some of the buildings in the street (40%) is remaining difficult, Figure 30 shows the situation based on all currently gathered information.

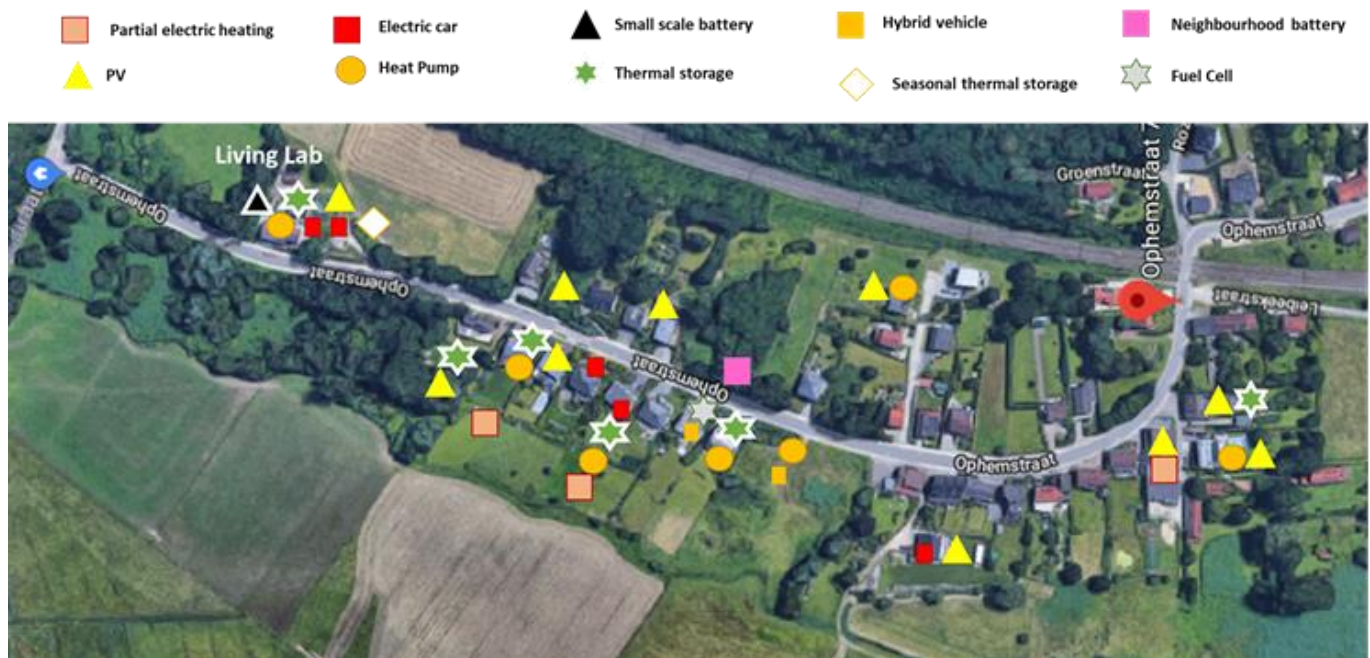


Figure 30. Technologies list in Oud-Heverlee demo.

4.1.2 Description of the different technologies

Solar PV

Currently, there is nearly 50 kW of PV installed. 10 of the 50 kW, those at site of Th!nk-e, are not connected to the grid. Within the next year, a group purchase of solar PV will be organized in the community. At this moment, it is estimated that 15 kW of new PV will be installed through the group purchase. The characteristics of the existing PV systems are:

Technical specifications

Installed Power: 40 kW of grid connected PV systems and 10 kW of DC (non-grid) connected PV.

Availability: Seasonal and daily variations.

Forced off: for certain voltages ($>110\%$ or $<85\%$ of nominal grid voltage) and frequencies (starting from ± 0.2 Hz deviation from 50Hz) solar installations will automatically disconnect and stop producing electricity. These limits are imposed for all systems connected to the low-voltage grid by the distribution grid operator.

Control strategy

PV systems are not actively shutdown or modulated.

Fuel cell

Used as a cogeneration heating unit in one of the households using natural gas. The unit is heat-demand driven, meaning that it generates electricity as a by-product. Nevertheless, because the system has a storage tank, the possibility exists to interface with the fuel cell and use it to generate electricity when there is limited DERS available in the energy community. It is to be seen if the low electric output (0.75 kW) is worthwhile integrating in the smart controller. The characteristics for the fuel cell are specified in the followings.

Technical specifications

Power: 0.75 kW_e / 11.4 kW_{th} combined heat and power (CHP)

Control interfaces: possible through an online application

Availability: the fuel cell is a CHP device and is thus heat-demand driven. Most power will be produced during the winter, but domestic hot water is also produced with the unit so it will not be as seasonal as purely space heating devices.

Maximum time on: fuel cell can only run for 3 hours consecutively; after this it must start a cleaning cycle.

Minimum time off: time for cleaning cycle after a heating period.

Forced on: possible if temperature in the boiler allows it but likely not worth it for such a small power generation.

Control strategy:

On/Off or Modulation: On/off because the electric generation cannot be modulated.

Heat pump

Three inhabitants of the demo site use heat pumps for space heating. Additionally, 5 hybrid heat pumps will be installed in other inhabitants' home. Of the three existing heat pumps, two cannot be controlled directly. This is due to the design which limits direct control. The only identified method to control these two heat pumps is an indirect method through the smart thermostat of these heat pumps. The characteristics of the existing heat pumps are described below.

Technical specifications

Range of powers: 3-5 kW_e

Control interfaces: currently installed heat pumps can be controlled indirectly through the room thermostat (Honeywell)

Availability: seasonal availability: in summer the heat pump is not available. In winter it is especially available to turn it off for one or two hours. In autumn and spring, it is very usable for both turning on and off.

Maximum time on: none

Minimum time off: none, although frequent on/off cycling of a heat pump causes accelerated aging

Forced on: indirectly possible through thermostat but no guarantee heat pump will be activated and no feedback from device to confirm.

Control strategy

Control signals: indirect control possible through the thermostat

On/Off or Modulation: On/Off control

Domestic hot water boiler

There are currently two domestic hot water boilers identified in the street. These systems will likely be replaced by Glen Dimplex boilers which are capable of smart control. The other option would be to retrofit these boilers with a system that makes them "smart". The characteristics of the two boilers in the street are specified below.

Technical specifications:

Range of power: 1.2-2.5 kW

Control interfaces: indirect control through a relay or through the OpenTherm protocol (if present).

Energy content: 1-6 kWh (0.06 kWh/l for $\Delta T = 50^\circ\text{C}$)

Availability: no seasonality and availability strongly related to usage (low usage → low availability). During a pilot in Belgium (Linear³³) the availability over the whole day to turn the boiler on (left) or off (right) has been plotted empirically in Figure 31. From the figure it can be seen that domestic hot water boilers provide more flexibility in the 'turn on' mode than in the 'turn off' mode.

Max delay time: depends on hot water usage (consumption pattern will have to be learnt)

Forced on/off: yes, is possible.

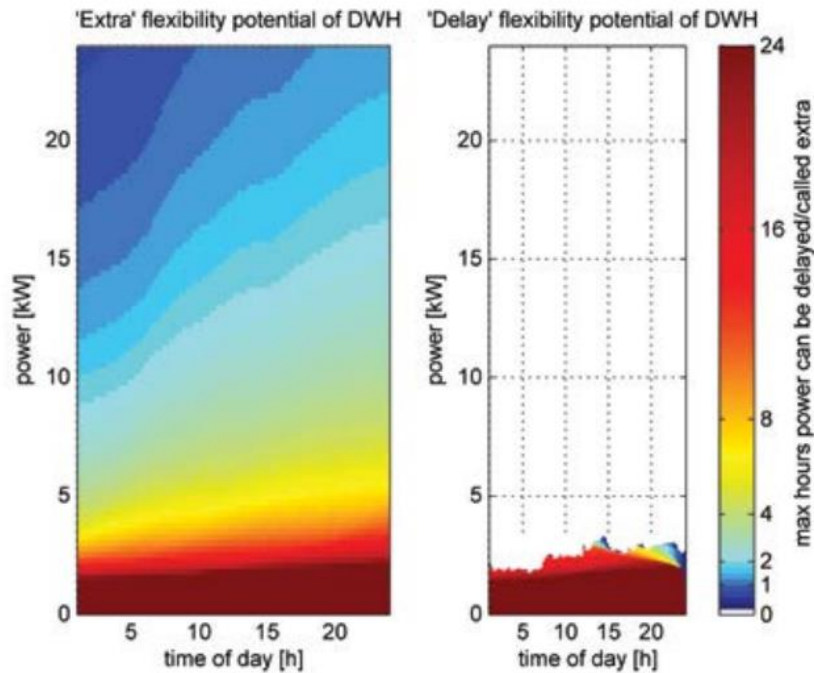


Figure 31. Flexibility potential of 10 DWH heaters analysed in a pilot test (Linear project³²). The *turn-on* flexibility potential is shown on the left and the *turn-off* (delay) flexibility is shown on the right.

Control strategy:

Control interfaces: relay control will be used (and perhaps OpenTherm, TBD)

Electric vehicles

The neighbourhood currently has four homes with electric vehicles. In total there are five vehicles with one site having two EVs. There are three homes fitted with four 22 kW charging poles. The power consumed by these poles is limited to the subscription of the corresponding homes.

Technical specifications

Range of power: four poles at 22kW but limited in power to not exceed the subscription of the household

Control interfaces: digital signal which is delivered by the platform of Keba

Energy content: depending on the car and state of charge 10-90 kWh.

Availability: depends on user set-points and car availability. During a pilot in Belgium (Linear) the availability over the whole day to charge (left) or delay charging (right) the vehicle has been plotted based on the users' preferences in Figure 32.

³² Linear Project (<http://www.linear-smartgrid.be/en>)

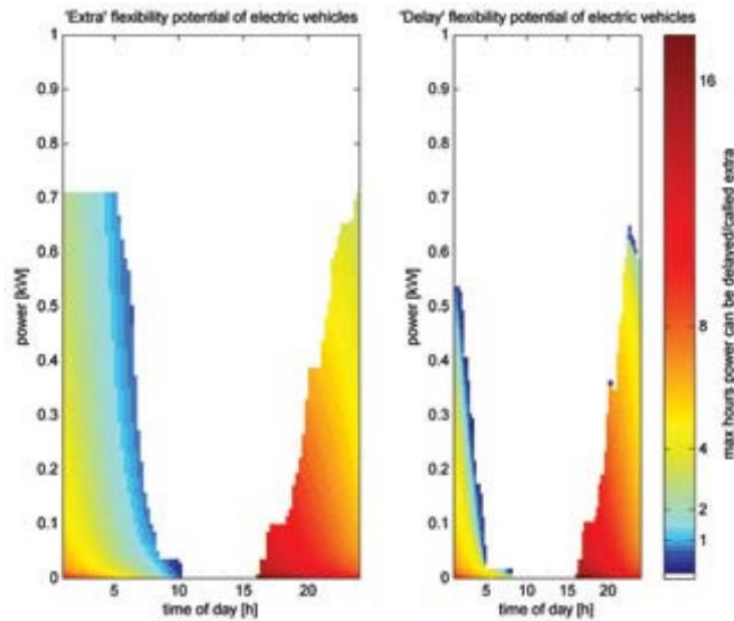


Figure 32. Flexibility potential of 32 electric vehicles based on users' preference (Linear project³³).

The maximum potential to charge (left) and delay charging of the electric vehicle has been estimated through taking the maximum potential based on the presence of the vehicles and has been illustrated in the figure below (Figure 33).

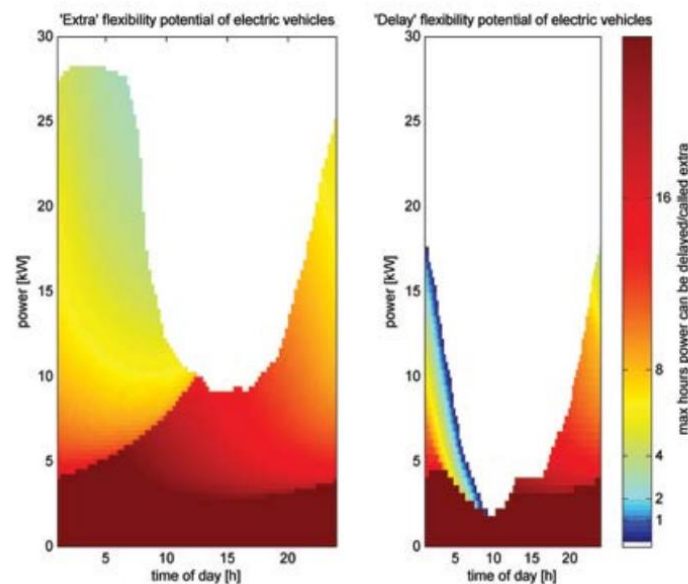


Figure 33. Flexibility potential of 32 electric vehicles based on maximum potential (Linear project³⁴).

Max delay time: depends on the demand of the user

³³ Linear Project (<http://www.linear-smartgrid.be/en>)

³⁴ Linear Project (<http://www.linear-smartgrid.be/en>)

Information availability: if the state-of-charge of the electric vehicle is unknown, the optimization may become more difficult as to not infringe on the comfort (having sufficient energy stored in the vehicle before next use) of the users.

Reaction time: within several seconds after command is given

Control strategy

At the moment the control strategy is a voltage-based charging.

Control interfaces: local control based on the voltage of the grid (high voltage measurement is an indirect means of measuring PV production or vice-versa the energy consumption in the neighbourhood).

Home battery system

There is currently one home battery system active in the neighbourhood (on the site of Th!nk-E). Other home batteries may be installed during the pilot, depending on how many other assets can be placed at participants' homes and their willingness. The characteristics of the home battery system currently present are specified below.

Technical specifications

Power: 18kW

Control interfaces: digital BYD platform, WiFi connected

Energy content: 50 kWh

Technical constraints: maximum power, energy content

Information availability: if the state-of-charge of the electric vehicle is unknown, the optimization may become more difficult as to not infringe on the comfort (having sufficient energy stored in the vehicle before next use) of the users.

Reaction time: within a second

Control strategy:

Control interfaces: through the BYD platform the battery power set-point can be adapted and information such as the state-of-charge can be retrieved.

4.2 New technologies to be installed for the DSM schemes

4.2.1 Smart Controller

The smart controller in the Oud-Heverlee demo-site will be based in the common architecture defined in section 3.2.1. In this case the optimal control will have a special focus on power-quality and comfort boundary conditions due to the typical characteristics of Oud-Heverlee local energy community.

Most of the controlled devices on the demo are home appliances or systems related to domestic user. So, it will be very important for the smart controller the users comfort as a "direct" objective of the optimization function, not only as an aggregated demand. In this sense demand side management can take into account single users flexibility or needs and take advantage of the controllable devices installed in the houses.

On the other hand, Oud-Heverlee demo has a strong focus on grid stability due to the grid configuration and the weak connection to the main grid. Smart controller will also balance the demand to guarantee that grid stability through load shifting (specially for EVs) and thanks to the neighbourhood battery.

OLAF backend system

As previous acquisition and measurement systems have been deployed in this demo under a backend system used by Laborelec, it will be also used for the smart controller deployment. This backend system is known as OLAF (OnLine Application Foundation) (Figure 34) and it contains many basic applications which are commonly used for different projects. An example of this is the historian application which stores data in a pre-defined manner. Another commonly used *block* in OLAF is the API-management application which is used to communicate specific

data in a specific format with external partners in an agreed on manner and that can be used to integrate modules owned by different providers. A final example of a commonly used block is the solar forecasting block that uses data from the Belgian TSO (Elia) to deliver a solar generation forecast. Besides the commonly used blocks, there are also specialized blocks which are likely only to be used in one project or for a specific client. The optimization block, containing the custom objective function of the Oud-Heverlee Energy Community will be one of these specific blocks developed for MUSEGRIDS project. A block which makes an assessment of the grid health, the grid diagnostic module, will also be a new specific block.

Constraints imposed by existing systems

Due to the ongoing EU project STORY, there are several existing constraints which must be taken into account. There will be four main elements to take into account: the STORY-ABB battery being installed on the street, the existing EV-charging poles and their control, the existing control system for the STORY-assets, and the existing heat pumps:

- Existing ABB neighbourhood battery: this battery will be controlled to improve the power quality of the local grid. A control strategy which allows multiple objectives (improve power quality and raise self-consumption) and/or direct control by the ENGIE control system.
- EV-charging poles: the primary limiting factors of these charging poles are that they do not communicate on the state-of-charge of the vehicle. Therefore, the poles are being controlled through a local voltage measurement. With this strategy, the poles will charge very slowly or not at all if the local voltages are low and vice-versa when the voltages are high. Nevertheless, the charging poles have communication options so these can be integrated in the control system at a later stage.
- Th!nk-E control system: the backend of the control system currently being used for the STORY project is being operated and maintained by Enervalis. The transition from one control system to the other (from Enervalis to OLAF) should not be difficult because the devices are all maintained by Th!nk-E.
- Existing heat pumps: these heat pumps have proven difficult to integrate in the control system. The only feasible method has been through the smart thermostat which controls these heat pumps. In this setup, the control variable is the temperature setpoint. It has been shown that such a control is not a very robust control method, because a significant delay can exist between a change in the temperature setpoint and an activation of the heat pump.

OLAF: OnLine Application & algorithm Foundation maximizing synergies and capitalizing on state-of-the-art technologies

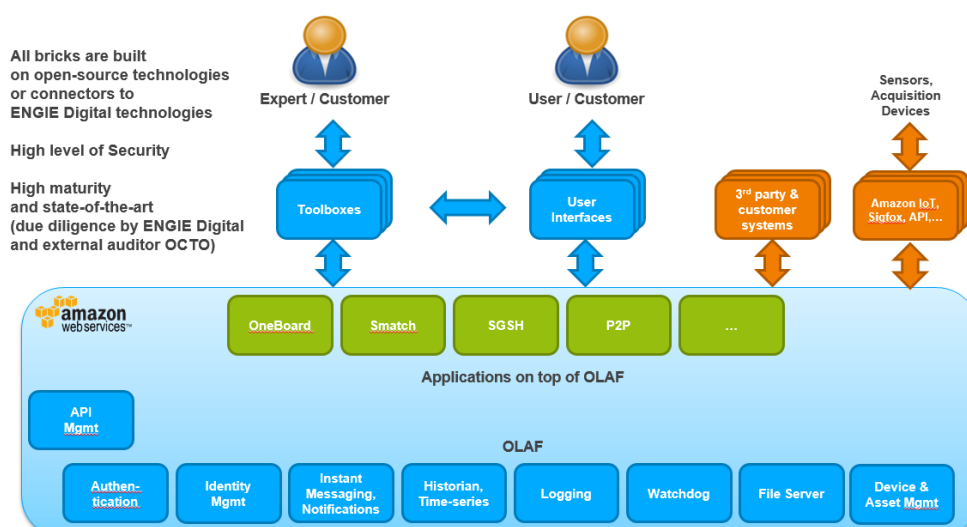


Figure 34. OLAF system

4.2.2 Electric heating technologies

It is planned to install 3-4 electric water cylinders by GDHVI, but the exact location is still under definition. Their specifications are the same as described in Section 3.2.2.

4.2.3 V2G and V2B technologies

The choice of V2G chargers has not been completely fixed yet, but a preliminary decision has already been made. The company in question, EVTRONIC, has recently been acquired by EVBOX, a subsidiary of ENGIE. In the following paragraph a presentation will be given of EVTRONIC together with the likely characteristics of the charging hardware.

EVTRONIC has several charging solutions, from AC low power up to DC 350kW. The DC chargers by EVtronic are articulated around a central unit and eventually additional satellites.



Figure 35. Evtronic charger.

In the 50kW range, the central unit (QuickCharger) contains the electrical protections, the EMC filters (passive), an isolation transformer, the power converter (1 bidirectional AC/DC and 3x DC/DC) and several charging options (normal “Shuko” type connector, AC Mode 3, DC Chademo, DC Combo), that can be present or not depending on the customer needs; optionally it can contain a modular storage battery.

The quickcharger satellites can be connected to the QuickCharger through CAN and Ethernet connection. The satellite can deliver 43 kW AC/ 50 kW DC. The Quickcharger and its satellite both can communicate by GPRS or Ethernet based the OCPP 1.6 standards.

EVTRONIC has developed a combined solution EV charger + integrated stationary battery, with a patented charging/discharging process. Up to 6 modules of 600 Wh batteries (2, 3, 4 or 6) can be added, more is possible with an additional architecture.

Those added batteries to the charging point bring two main advantages: i) to hold the power from the grid below a certain limit for economic reasons (smaller connection tariff and less yearly connection fees), and ii) it also ensures a constant power consumption from the grid, in order to offer a more predictable use of the grid.

During the first phase of the charging cycle, the power demand is around 50kW: 36kVA are taken from the grid, and the rest is taken from the battery.

During the second phase of the charging cycle, the power is rapidly decreasing, and when it is below 36kVA, the grid continues to deliver 36kVA, a part being used to charge the car, the rest being used to recharge the stationary battery.

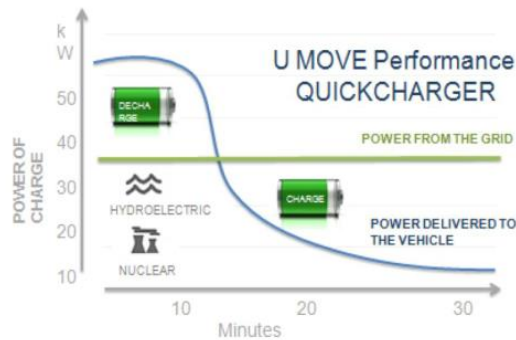


Figure 36. Quickcharger performance.

Technical specifications

It is likely that a hardware similar to the Quickcharger will be used for the vehicle to grid applications. The technical specifications are the following:

- Power: two chargers per charging pole with a total maximum power of 50 kW, depending on discussion with the DSO
- Connection: DC chargers connected directly to the battery voltage
- Communication:
 - Protocol used now for V2G is based on OCPP 1.6 to allow bidirectional charging
 - Information parameters between car and charging point is based on ISO 15118-2 for CCS DC fast charging
 - Custom V2G protocol used in projects with Renault

Control strategies

- Use of battery within 20-80% of state-of-charge and within user constraints on time/energy limitation.
- Control through SMATCH, ENGIE's platform for electric vehicle charging
- Constraints: SoC range (20-80%) and user constraints (SoC at X% by time T)
- Input/output control variables: Out: state-of-charge, maximum time before amount of energy E need to be charged; In: power setting

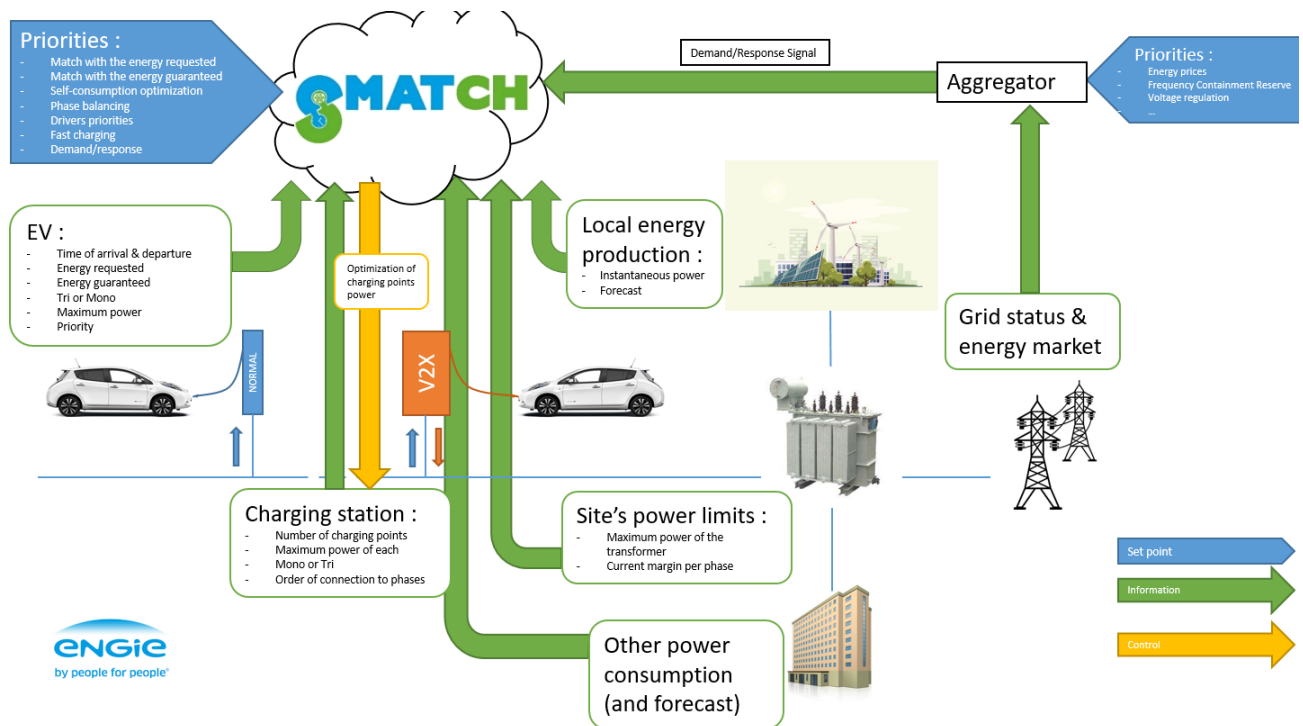


Figure 37. ENGIE's platform for vehicles charging.

Applicability in the DSM schemes

- Pros:
 - The V2G systems can both charge and discharge meaning it can act as an additional storage system
 - Can deliver voltage regulation and phase unbalance services.
- Cons:
 - Will be limited by the demand that needs to be fulfilled
 - The availability may be limited and is stochastic, depending on the usage of the vehicles
 - Will be a public, shared car. The profile of such usage is significantly different from a classic private vehicle
 - Reaction to voltage dips will likely be impossible due to required reaction time

4.2.4 Neighbourhood battery

Technical specifications

The battery system to be installed in the Oud-Heverlee demo site is known as the PQplus from ABB. Its key selling point is the inverter which can deliver power quality improving services in addition to energy storage. A schematic of the battery is shown below (Figure 38):

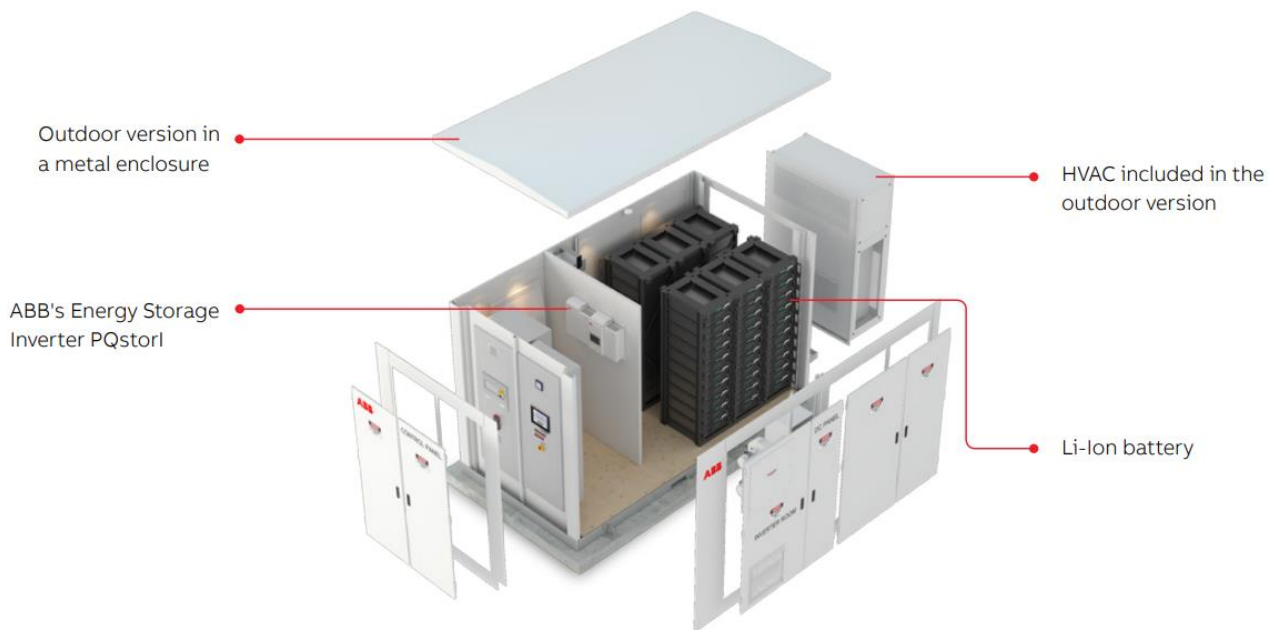


Figure 38. ABB battery storage.

Its general specifications are the following:

- Power: 100 kW
- Energy: 68.5 kWh
- AC voltage: 380-415 V_{AC} (three phase connection)
- DC voltage: 635-821 V_{DC}

Control strategies

The following control strategies can be implemented with this device:

- Peak shaving
- Backup power
- Power Quality (reactive power and harmonic compensation ability)
- Capability to operate in islanding mode with blackstart feature (optional)

Its in/out control variables are: State of charge of the battery, Temperature, Grid voltage per phase, Current/power per phase.

Applicability for DSM schemes

The neighbourhood battery shall be used for several use cases and will also be turned off during several periods as to determine the added value of the other assets without the neighbourhood battery. One possible restriction which may occur is the lack of a measurement from the distribution cabinet which is feeding the street. This measurement would be needed.

Positive and negative aspects of its application are listed below.

- Cons:
 - Self-consumption maximisation is limited by the size of the energy reservoir and the maximum power of the inverter.

- If there is no measurement of the current flow from the distribution cabinet (which feeds the neighbourhood), the power quality improving features may be limited.
- Pros:
 - Can deliver all investigated DSM objectives, i.e Power quality improvement (Voltage regulation, Phase unbalance, Voltage dips, Harmonics compensation, active filter (not investigated during the pilot)); Self-consumption maximization; Optimisation of electricity costs.

4.2.5 Hybrid heat pump

Technical specifications

There will be 5 hybrid heat pumps installed in the neighbourhood in the coming year. Hybrid heat pumps are low-power heat pumps that can deliver heat either from electricity or from natural gas. This allows the heat pump to easily bridge days that are very cold due to gas standing in as backup. Another advantage is the overall high efficiency without requiring the system to be dimensioned for the coldest possible day. These will be placed in homes with underfloor heating due to the low temperature that can be used for such a heat distribution method. The device in question is a Daikin Altherma Hybrid Heat Pump. An illustration of the product has been taken from the data sheet (Figure 39).



Figure 39. Daikin Altherma Hybrid Heat Pump.

Its general specifications are listed below:

- Electric power: $0.87\text{--}2\text{ kW}_e$
- Thermal power: $4\text{--}7.4\text{ kW}_{th}$
- Energy storage (in underfloor): depends strongly on the house and its current state (temperature)
- Communication: an external WiFi controller will be added to control the heat pump through the platform
- Input/output variables:
 - Input: operation mode (heating/cooling/auto), power source (electricity or gas), output temperature of the working fluid, ...
 - Output: almost all variables pertaining to the heat pump (status, in/out temperature of working fluid, inside/outside temperature, ...)

Applicability for DSM schemes

Hybrid heat pumps are very flexible due to the characteristic of being able to switch seamlessly from electricity to gas. Therefore, if the grid requires it or electricity is expensive for the moment, the electricity consumption can be completely avoided without any loss of comfort. Thus, it is completely flexible. On the other hand, the electric power it requires (0.87-2 kW) is very low. It is to be seen how much this low-power, high energy device will be able to contribute for each of the investigated DSM objectives. There will be 5 hybrid heat pumps installed, each in a different home. This will allow an assessment of which house- and consumption profile is most suitable for which objective.

4.3 Data analysis

For the consumption data of the neighbourhood, there are two solutions currently being used to gather data. In a later stage of the project, the local DSO is planning to provide a number of smart meters which will be used to collect data and monitor the energy community. In the following section, each solution will be presented and, finally, an analysis will be made of the possible DSM objectives for each measurement solution. The table below gives a summary of the three measurement solutions used in the Oud-Heverlee site.

Table 6. Measurement data, communication method, and granularity for Oud-Heverlee demo.

	Parameters measured	Communication	Granularity (Samples/second)
ABB Platinum Power-Quality meter	Voltage, current, phase angle, harmonics,..	REX gateway (WiFi, Ethernet or 3G)	Max: 60 Used: 0.2
Geco optical sensor	Energy	ENGIE gateway (3G)	Max: 1 / minute Used: 1 / minute
Belgian smart meter			
- P1 interface	Energy, power	ENGIE gateway (3G)	Max: 1 S/s Used: 1 averaged / minute
- S1 interface	Voltage, current	TBD if used	Max: 4000 S/s Used: TBD if used

In the Oud-Heverlee site, 2 main types of measurement data will be collected. The first is general electricity consumption data with a granularity of 1 data point per minute. The granularity of this data will also be decreased to 1 per 15 minutes to assess the effect it has on the outcomes of the different modules in the control architecture. The second type of data is high-frequency power-quality data. This data can be used to identify and measure different power-quality issues.

The general electricity consumption data will be collected by an ENGIE gateway and either an optical sensor for a Ferraris energy meter or a dongle, which reads the P1 interface of the smart meter which will be used in Flanders. These solutions can be considered low-cost; the cost for the hardware is less than €300 and the data requirements for a 15-minute transfer interval amounting to 0.35 GB per month (including data need for encryption at each data transfer). The power quality data will be collected by an ABB “platinum A43” meter and the data will be pushed by a gateway provided by THNK, named REX. This solution is expensive; the meter and gateway cost ~ €1000 and the data requirement amounting to 4.25 GB per month (without encryption data).

4.3.1 Low-cost metering

As mentioned above, a low-cost solution has been prepared for two metering systems; one for a classic Ferraris meter and one for the Flemish smart meter. Central to both of these solutions is a Raspberry Pi, which is low-cost mini-computer.

In previous projects, the Raspberry Pi was coupled to the participants' internet router either through WiFi or Ethernet cable. The experience of using the participants' internet router has been troublesome:

- It is less secure, especially with WiFi, because there is a connection to the participants' internet which could become a security breach
- Connection is lost if the participant changes their WiFi password or changes internet provider
- WiFi connections are generally unreliable

Therefore, the choice has been made for a solution with GPRS (3G) connectivity. In terms of cybersecurity this solution delivers more security. Although the GPRS network also has some down time, it is generally more reliable than a WiFi connection.

Effect on forecast and DSM schemes

Forecast of residential consumption is difficult due to the stochastic nature of the consumption. Individual homes require a lot of effort to forecast and, even then, have a large uncertainty. In the Oud-Heverlee Energy Community, energy will be forecasted for the community as a whole. Generally speaking, the larger the group of residential consumers the more accurate a load forecast is for the group as a whole. The number of participating houses (around 40) will deliver useful return on experience on the efficacy of forecasting for small groups of consumers. DSM objectives: the following bullet points will elaborate on the relation between the data available (energy consumption every minute) to the effectiveness of DSM objectives. The effectiveness will be related to each of the objectives of the DSM schemes. The main limiting factor for power quality objectives is the lack of voltage measurement. The effect for different DSM objectives

- Self-consumption: the one-minute granularity of consumption data is enough to enable control to increase self-consumption in the neighbourhood. In the pilot, increasing the granularity of the data fed to the controller to 15 minutes will be investigated to see the effect on the controller.
- Voltage regulation: Even though there is no voltage measurement, it will still be possible to estimate the level of the voltage in the grid with only consumption data. With historical data, it will be possible to estimate voltage for different levels of consumption/production of the whole grid. The level of effectiveness of voltage regulation with only consumption data is one of the elements to be assessed during the pilot project.
- Phase unbalance: In this case, the effectiveness of dealing with this power quality objective depends on the data available in the street. If it is known which house is connected to which phase, then an estimation can be made of the voltage in each phase. As it stands, the DSO in Flanders does not have information on which house is connected to which phase. Therefore, this information could only be available through a power quality metering campaign.
- Voltage dips: Voltage dip events can only be measured through a direct voltage measurement and cannot be estimated as with phase unbalance and voltage regulation.

4.3.2 High-quality metering

To measure power quality parameters in the homes of participants, ABB A43 platinum meters have been used. These meters can measure important parameters such as active-, reactive power, harmonics and Total Harmonic Distortion (THD). The houses fitted with these devices are currently the following (blue circles) in Figure 41.

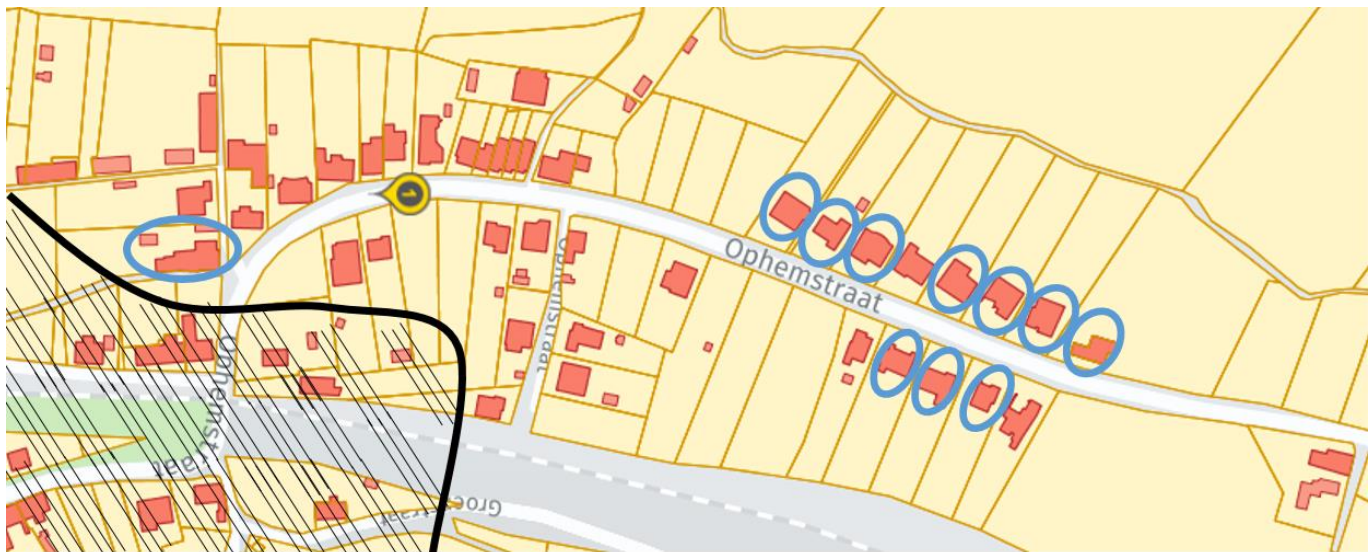


Figure 41. Houses with high quality meters.

All other participating houses will be fitted with the ENGIE solution. An example of the wiring of the meters is shown below (Figure 42):



Figure 42. THINK-E REX meter.

An example of some of the data (Voltage, Power Factor, and active power) captured by the ABB meters for three phases simultaneously is shown in Figure 43.



Figure 43. Sample data.

Effect on forecast and DSM schemes

The granularity of the forecast of residential consumption is never larger than the granularity of the historical data which feeds the forecaster. Nevertheless, the load forecasts will primarily be used for *energy* purposes, and thus, one-minute forecasting is not required and would not deliver very good estimates anyway due to the stochastic nature of residential electricity consumption. For the grid diagnostic module, it will be investigated if a higher granularity of data will provide better control and forecasts with regards to grid health.

the following bullet points will elaborate on the relation between the data available (energy consumption every minute) to the effectiveness of DSM schemes. The effectiveness will be related to the each of the objectives of the DSM schemes. The main advantage for power quality objectives is the presence of a voltage measurement. Although there is a high granularity of data available, the energy consumption data will only be sent out at 1 minute intervals to reduce data requirements.

- Self-consumption: the one-minute granularity of consumption data is enough to enable control to increase self-consumption in the neighbourhood. In the pilot, increasing the granularity of the data fed to the controller to 15 minutes will be investigated to see the effect on the controller.
- Voltage regulation: the voltage measurement of this meter allows for the identification of moments where the voltage is too high and too low. A key element determining the effectiveness of strategies to resolve the voltage issue will be identifying phase to which the different assets/houses are connected to.
- Phase unbalance: this will require a voltage measurement on each of the phases and preferably all three at one single location. In the Oud-Heverlee case there is are luckily three households where a measurement on all three phases is taking place. This will allow us to also momentarily disregard this measurement and investigate the effect on the power quality management. It remains to be seen if enough assets (excluding the neighbourhood battery) are available to resolve any possible unbalances.
- Voltage dips: Can be identified but likely that only the neighbourhood battery will be able to deliver a response quick enough. This is due to these events usually only causing a low voltage for several seconds, and thus, the reaction time of the controller would be insufficient.

4.4 DSM schemes and objectives

In the Oud-Heverlee demo-site, two main objectives will be set for the smart controller: cost minimization and power quality improvement. The schemes which will be used to achieve these objectives are summarized in the following two sections.

4.4.1 Self-consumption maximisation and cost minimization for the community

The self-consumption objective is an objective that is intrinsically dependent on the cost minimization objective. If the correct regulatory framework is present in the area, then consumption of local energy will deliver some cost savings compared to buying energy from the grid. The relation to the gas-vector is also present in the Oud-Heverlee site through hybrid heat pumps and fuel cells. The hybrid heat pumps will allow a shift from gas to electricity or vice-versa for the same level of comfort. This will allow cost or CO₂-based optimisation.

From historical data, it is possible to investigate the need for an increased self-consumption. Figure 44 shows a sample of the aggregated net-consumption and PV generation for 6 participants in the Oud-Heverlee neighbourhood from June 1st to August 13th 2018. Two of the participants have PV installations (a total of 15 kW) and 4 participants only consume electricity. The sample considered in this graph has a ratio of PV kilowatt per participant higher than the ratio which would be achieved if all (40) homes of the street are considered (2.5 PV kW per participant versus 1.25 PV kW per participant or 1.625 if 15 kW of PV, to be bought by the group purchase foreseen on the street, is included in the calculation).

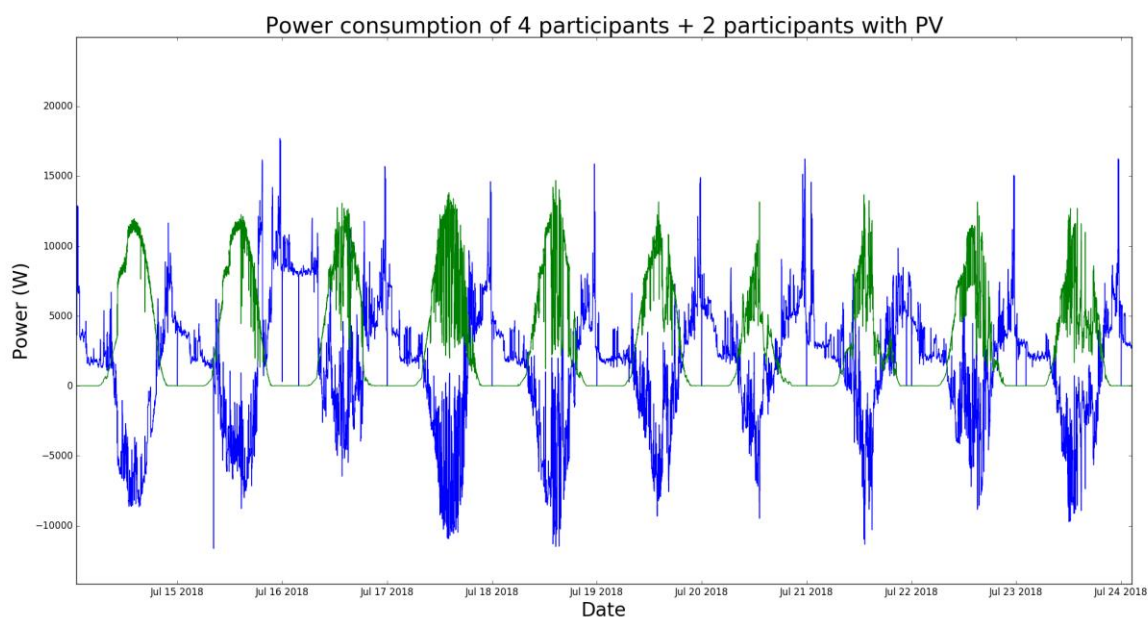


Figure 44. Sample from aggregated net-consumption (blue line) and total PV production data for 6 participants (green line).

Figure 45 illustrates the average aggregated net-consumption of the 6 participants for each hour of the day. From this figure it can be seen that a significant part of the PV production is injected into the grid. This forms a first indication for the need to increase self-consumption.

It should be noted that the 6 participants in the sample are not representative of the entire street. As mentioned above, the PV per inhabitant is higher than the expected average in the street. It is likely that, in terms of consumption, there is also misrepresentation in the sample. As shown in Table 7, the average daily consumption in these 6 households is 16.2 kWh/day. The average daily consumption in Flanders is closer to 10 kWh/day³⁵. Therefore, it is likely that, as more houses are aggregated, the average daily consumption will converge toward the 10 kWh/day figure. Table 7 summarises the sums of the measured values and shows the self-consumption and self-sufficiency of the sample for each correction applied (load and/or PV downsized by a factor). The corrections are just illustrative, the effect of combining multiple load profiles will have a much different effect than simply applying a scaling factor. The two most realistic scenario's considered (the unaltered sample and the scenario with both load and PV corrected for) indicate that there is quite some room for improvement towards self-consumption and self-sufficiency (more than 50% increase possible in self-sufficiency for both). However, these data only show 2 and a half months and a limited amount of users. Therefore, this exercise shall be performed again when more data are available.

³⁵ <https://www.engie-electrabel.be/nl/blog/oplossingen-voor-thuis/gemiddeld-elektriciteitsverbruik-belgie>

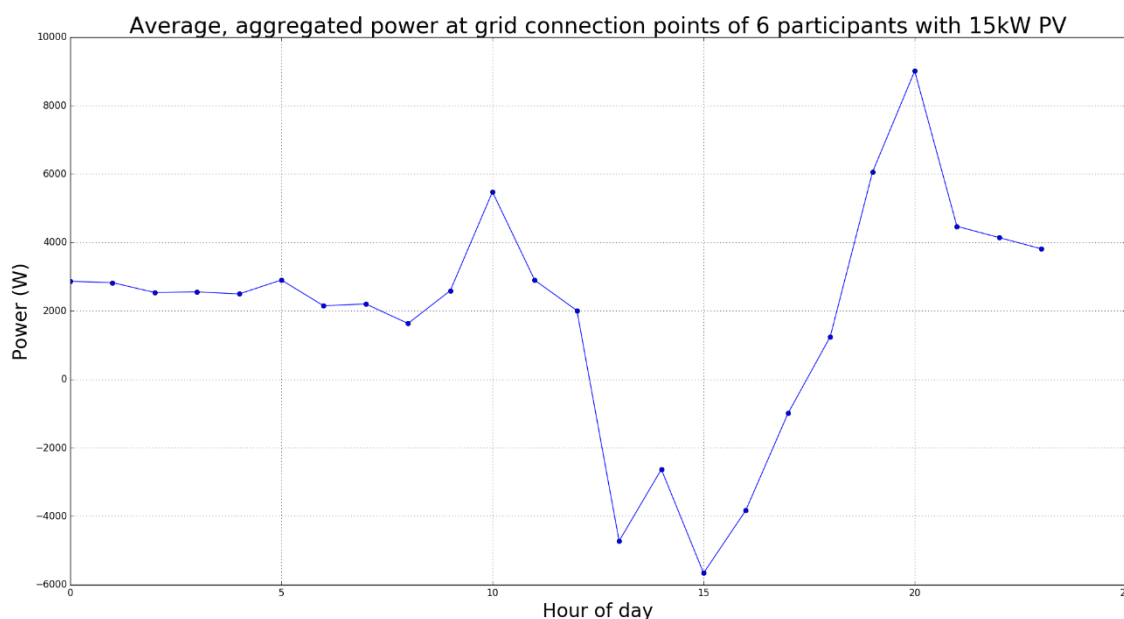


Figure 45. Average, aggregated net-power consumption at each hour of the day for the investigated sample.

Table 7. Summary of key consumption and generation figures for the concerned sample.

	Sample: 4 consumers and 2 PV owners [kWh/day/home]	Same sample with PV scaled down ³⁶ [kWh/day/home]	Same sample with load scaled down ³⁷ [kWh/day/home]	Same sample with PV and load scaled down [kWh/day/home]
PV-generation	10.3	6.7	10.3	6.7
Total-load	16.2	16.2	10	10
Total-export	4	1.5	5.7	2.7
Net-grid consumption ³⁸	9.9	11.1	5.4	6
Self-consumption	61%	78%	45%	60%
Self-sufficiency Actual/maximum	39%/63.6%	31%/41.3%	46%/100%	40%/67%

In the enumeration below, a summary is given of the different methods with which these objectives will be reached:

- Based on the local generation, **automated control** of flexible & controllable assets in members' homes within the boundary conditions of comfort. Devices to be considered:
 - Domestic hot water boilers and heat pumps
 - Home battery system

³⁶ The ratio of PV versus participants in the original sample was 2.5 and the ratio for the whole street will be 1.625 if 15 kW is added due to the group purchase. If the PV is scaled down by 1.54 (=2.5/1.625) then this would better represent the future situation of the street

³⁷ The energy consumption of the houses in the sample is significantly larger than the average in Flanders, which is about 10 kWh/day (<https://www.engie-electrabel.be/nl/blog/oplossingen-voor-thuis/gemiddeld-elektriciteitsverbruik-belgie>)

³⁸ Sum of positive (consumption) energy flows with PV generation subtracted for the sample as a whole

- Electric vehicle chargers
- **Active control** of other energy consuming devices and activities **by the members themselves** by means of signals which will either be made available on the user interface (real-time status) or through fixed daily schedules, dependent on the weather, that are valid for an extended period (a systematic, average status):
 - Load shifting of white goods appliances (washing machine, dryer, dishwashing machine,...)
 - Examples of energy reduction when production is low:
 - Reduce temperature in house if there is electric heating (i.e. heat pumps)
 - Wait to run the dishwashing machine
 - This will not only reduce their own bill but could have an effect on the community as a whole because, for example, the little PV energy available can be better shared within the community.
- **Automated control of shared assets** in the neighbourhood:
 - V2G charging stations
 - Neighbourhood battery

4.4.2 Power quality optimization

Besides the neighbourhood battery, which will specifically look at power quality issues and relieve them, the actions from the previous section will also improve power quality. The voltage in the street is strongly related to the amount of consumption from the grid (low voltage) and simultaneous PV generation (high voltage). By using as much generated PV power as possible, the high voltages (mainly when power is being exported to the upstream distribution grid) will be reduced strongly. In the other case, when there is too much consumption from the grid and electricity prices are higher, reducing consumption and/or shifting consumption will put less strain on the grid at that moment.

The statements above are true in general, but certain special situations could occur as with phase unbalance. In this case, big and three-phase connected sources of energy such as the V2G chargers and neighbourhood battery shall be used to provide the needed balancing. It shall also be investigated if phase unbalance can be reduced by the combination/aggregation of many smaller loads by disconnecting the functionalities of the V2G charger and neighbourhood battery.

Figure 46 illustrates the strength of the grid in Oud-Heverlee. It shows the RMS voltage of one of the phases during April of 2019 at the end of the line (at the last house of the street). The achieved voltages are within the allowed ranges according to the grid code (+10% and -15% of 230V), but they clearly get close to the limit. The month of April is also a rather *soft* month in terms of heating loads, meaning that there will likely be some situations found exceeding the voltage limits when more of the data is analysed. Nevertheless, the voltages fluctuate very strongly during the day which indicate that the local grid is weak. This is not surprising since the power cables were initially designed to serve several farmers (40 years ago) and now serve over 40 houses which have significantly large loads such as heat pumps, electric vehicles, and electric stovetops. With the introduction of new PV systems and more electric loads, the need for a central, smart control seems evident.

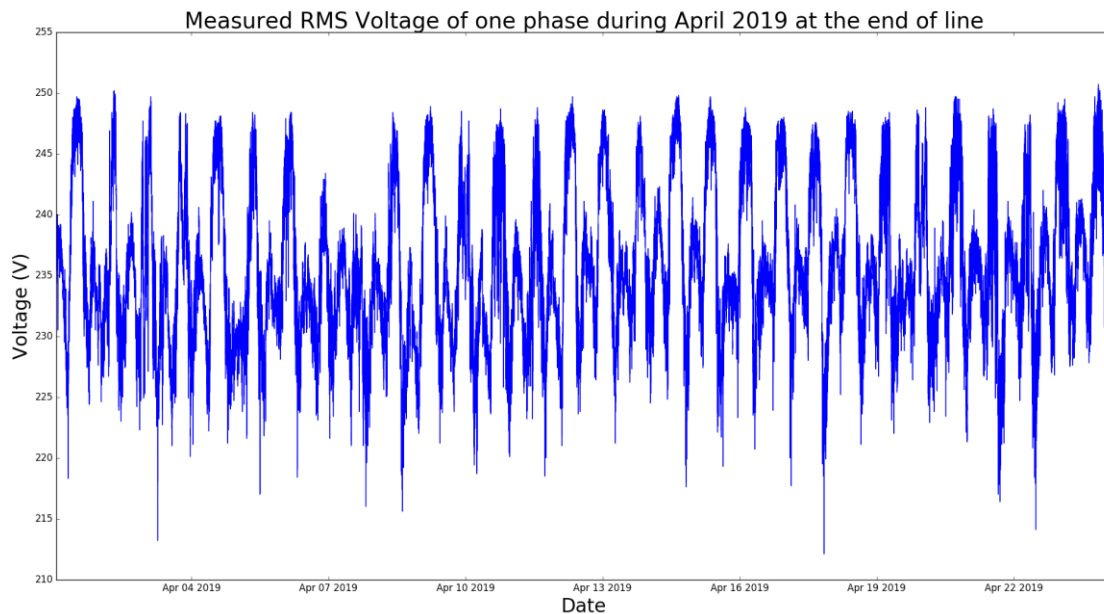


Figure 46. RMS voltage measured at the house furthest away from the distribution transformer during April 2019.

4.5 User engagement strategies

The theoretical considerations described in the state of the art section make it possible to come up with meaningful and lasting user engagement strategies for the Oud-Heverlee neighbourhood.

4.5.1 Passive DSM

A first approach to DSM is to engage as little as possible with the end-user (in a role of energy consumer) and automate all non-point-of-use activities such as heating the house and charging the car. Although this method seems worry-free, care should be taken that energy consumers can be frustrated by the lack of knowledge on certain aspects of the DSM (eg. “why doesn’t my car charge right away?”). Practice theory warns us that practices are linked and that although it might seem that the end-user is not affected in one practice (eg. the delaying of starting the washing machine doesn’t affect the washing practice), he might still be affected in another (eg. “if the washing machine is not immediately emptied, I have to iron more”).

It seems therefore that this first approach to DSM highly depends on keeping the DSM as invisible as possible, which might not always be possible. In addition, these passive options offer only a fraction of the possibilities of DSM.

4.5.2 Active DSM

In a second, active DSM approach, the end-consumer is engaged to adopt the more reflexive persona of the energy citizen. From a practice theory perspective, this persona can emerge from one of the 4 elements: knowledge, meanings, technology and skills.

An easy-to-use user interface that shows participants’ energy consumption could be a first step to make end-users aware of how their everyday practices consume energy. It is important that the user interface is intuitive and simple to understand. To extend the possibilities of the consumption interface, end-users also need the skills to change their energy consumption practices. A newsletter can teach these skills with simple advice on how to lower stand-by consumption, how thermostats are best used and so on.

By putting the focus on microgeneration and by informing the end-users on how much microgenerated energy is available at which time of day, energy surfaces in a positive context of ownership and citizenship. An enabling

technology to inform the end-users about the availability of local energy could be a light in the living room that changes colour. A second enabling technology that changes the engagement could be a fake electricity bill that shows how much of the energy was generated by local sources.

As new technologies are added, such as vehicle-to-grid chargers, engagement to these technologies can be changed. For example, delayed EV charging could be seen as “giving electricity back to the household” (an ownership perspective) instead of “I am not allowed to charge my vehicle right away”.

In the coming months, the above high-level outlines will be further detailed into a concrete user engagement strategy. A user-interface where consumers can see their consumption will be developed as a first step. Next, different strategies can be defined to give the end-user knowledge and skills (through newsletter, get-togethers...), while at the same time attaching new meanings to certain practices.

Potential active user engagement strategies to be tested

The following summarizes some of the instruments that might be implemented to facilitate a behavioural change of the participants:

- Time of use scheme: a fixed time scheme will be communicated to the participants. This is comparable to the well-known peak/off-peak rates. A different scheme will be communicated at regular intervals, for each season for example.
- Indirect communication of the neighbourhood status: this technique would communicate a live, overall status of the grid in the user interface (UI). By checking the UI the participant will know if electricity is expensive (from the grid) or cheap (sourced locally) at each moment.
- Direct communication of the neighbourhood status: this technique uses a direct signalling method of the status of the neighbourhood. The participant will not have to look for the status on the UI themselves, rather an intuitive signal will be present at all times in their home. A possible implantation is a multi-coloured light bulb which will change colours corresponding to the status of the grid
- Status reports of the participants' behaviour: this method is based on regular communication to the participants on their own “performance”. A possible implementation would be with a mock-electricity bill which shows how much electricity they have been using from local sources. The bill would track the performance of the user over time so they can assess if any changes they make in their behaviour have an effect on their performance.

4.5.3 Overview of user engagement strategies

This section lists possible user engagement strategies to be implemented in Oud-Heverlee.

Motivation actions

- Mailing: to all neighbours, exposing the beginning of every new stage of the project, highlighting the opportunities (environmental improvement, innovation, example for other places...) that it generates. Briefing of the changes that will be shown during the presentation party.
- Street identification: a street-banner or vertical sign on the access to Oud-Heverlee, showing visitors and neighbours that they are part of something "special". A system of adhesions can also be designed to identify participating households.
- Party-presentation: a playful activity themed around energy, which seeks the adhesion of the neighbours to the project through theatrical performances, workshops for children, etc. Coherence between content and continent (fed with renewable energies, with reusable materials, local consumer products, etc.) should be maintained.

Communication actions

- Newsletter: periodical newsletter distributed to the whole neighbourhood. It would contain several sections, including one that presents other communities in Europe and the world where innovative solutions are used to improve the integration of renewables; interviews or testimonials of local references (local soccer club, shops, hotels, Don Bosco center, etc.); project results, etc.
- Presence in local media: If they do exist, it would be interesting to engage them to make the international project in which the locality is included known to the neighbourhood, giving relevance to the example that its own involvement could represent elsewhere.
- Visibility of progress: a system will be sought to make the progress of the project visible to the users, measured through a numerical indicator that reflects the environmental benefit achieved (Ton CO2 avoided, local kWh consumed, etc.). These progress indicators would also be disseminated through the newsletter and in the local media.

Participatory actions

- Implementation of a local participatory work group: at the presentation party, the attendees would be summoned to be part of the participatory work group that conducts the project. A working plan could be established by them in order to define the communication actions with the rest of the neighbourhood throughout the project. This group could also evaluate the levels of participation, analyze the different proposed technologies and select the most appropriate technical solutions along with the staff, evaluate results, etc.

5 Conclusions

This report summarizes the main features of the two considered demo sites in terms of energy flexibility. The survey highlights that there are different assets that can be used to unlock the flexibility of the overall energy demand (not only the electricity demand). Indeed, the co-existence of several energy carriers in the energy systems helps to provide degrees of freedom in the system operation. Furthermore, even if the two demo sites have different peculiar characteristics, they contribute to show the implementation of several demand side management schemes that can be replicated and implemented in other similar circumstances.