2023

H2020 Auto-DAN Project: Enhance the Participation of the Community to Demand Response by Providing the State-of-the-Art Technological and Policy Solution

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Funder: European Union’s Horizon 2020 research and innovation programme under grant agreement no. 101000169

2023 International Conference on Future Energy Solutions (FES) | 979-8-3503-3230-8/23/$31.00 ©2023 IEEE | DOI: 10.1109/FES57669.2023.10182635

H2020 Auto-DAN Project: Enhance the Participation of the Community to Demand Response by Providing the State-of-the-Art Technological and Policy Solution

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Abstract— The growing demand for electricity in Europe has increased the need for a more flexible and sustainable power system. In recent years, Demand Response (DR) has emerged as a promising solution to meet this need, by providing an opportunity for residential and smaller commercial consumers to actively participate in the electricity market. This research paper investigates the potential for DR among the residential community and small commercial electricity consumers in Europe and identifies the technological barriers and drivers that impact consumer engagement with DR programs in Europe. The different DR opportunities are identified and validated at the six different demo sites in three different European countries: Ireland, Italy, and Spain. Four specific objectives of the DR applications are identified: 1). DR to avoid curtailment of renewable energy generators by the electricity grid operator 2). DR to optimize the energy efficiency of a central or district heating system 3). DR to limit the maximum power imported on a grid connection shared by several consumers 4). DR to maximize the level of self-consumption in a Renewable Energy Community (REC). The application of DR objectives will be implemented using a state-of-the-art community based Peer2Peer energy market platform and Digital Twin optimization engine together with the smart hardware infrastructure to enhance community engagement in DR. Finally, this paper suggests the improvements required in the Building energy performance standards and the Electricity Market design regulations to enhance the participation of the community in DR.

Keywords—Demand Response, Renewable Energy Community, Peer2Peer Energy Market, Electricity Market, Building Energy Performance.

I. INTRODUCTION

Residential and smaller commercial consumers play a significant role in the overall energy consumption of Europe. According to the European Commission (2021), the residential sector accounted for 25% of the total electrical energy consumption in the European Union in 2019. Furthermore, the demand for electricity in this sector is expected to increase by 27% by 2050 [1].

With the growing demand for electricity, there is a need for a more flexible and sustainable power system in Europe. Demand response (DR) has emerged as a promising solution to meet this need by enabling residential and smaller commercial consumers to actively participate in the electricity market

The European Union recognizes the importance of DR, stating that "DR can play a crucial role in ensuring the flexibility of the power system, allowing for greater integration of renewable energy sources and reducing the need for expensive and carbon-intensive peaking plants" [1]. Moreover, the International Energy Agency (IEA) highlights the benefits of DR, such as reducing peak demand, enhancing grid stability, and lowering energy costs for consumers [2].

There have been significant technology advancements in the recent years to enable new disruptive solutions for improving the energy efficiency and self-optimisation of existing buildings and the smart building and the smart grid are both key parts of the EU Strategic Energy Technology (SET) Plan [3].

In line with this, the Horizon 2020 project Auto-DAN(Deploying Augmented intelligence solutions in EU buildings using Data analytics, an interoperable hardware/software Architecture and a Novel self-energy assessment methodology) is aimed at self-assessing and self-optimising the energy performance of buildings using innovative IoT technologies. The aims are achieved by providing five experimental services to consumers within buildings (the end-users) across six sites in three countries and integrated through a common IoT platform centred around SenseIoTy platform, then demonstrate these services on the sites and analyse their performance with respect to building energy performance. The five services are presented in Table 1 and the six demo sites are presented in Table 2.

TABLE 1 THE FIVE AUTO-DAN SERVICES

Services	Single Line Description
Live Audit	Present to the consumer actual energy performance of the building (feedback)
Optimisation	Present to the consumer suggestions on how to improve the energy performance of the building (feed forward)
Insight	Present to the consumer energy usage of building components (systems, appliances)

Demand Response	The consumer responding to dynamic information provided by the seller or distributor of energy, by changing when and how much they buy
Fault Detection	Present to the consumer likely technical issues with building components (equipment, room, process)

TABLE 2 THE SIX DEMO SITES IN AUTO-DAN

Demo Sites	Description	Country	City/Town
Crannog-OCCA	Private Owner Housing Estate	Ireland	Dublin
Greenogue	Business Park	Ireland	Dublin
Palazzo Terragni	Theatre (1 consumer)	Italy	Lissone, Milan
Medea	Rental Apartment Block	Italy	Milan
UBU Student Accommodation	Rental Student Accommodation	Spain	Burgos
VideBurgos	Social Housing Apartment Block	Spain	Burgos

In this project, one of the main services for the end user customer is Demand Response (DR).

II. DEMAND RESPONSE

Demand Response (DR) is a method whereby the supply-side (sellers or distributors) aims to achieve a specific objective by influencing how much and/or when the demand side (consumers, buyers) buys the product (elicits a response from the demand side).

Suppliers can elicit a response in two different ways:

- Implicit DR: The supply-side varies the price, typically as a schedule of tariffs specified as part of the supply contract with the consumer: the Time of Use schedule (ToU) [4], also known as smart tariffs. Settlement is based only on how much the buyer buys and when, and not on the level of response. This method is closely associated with Demand Elasticity: the sensitivity of demand to the price [4]. Demand Elasticity for energy is typically low because they are considered basic needs with few alternatives [5]. This makes response relatively uncertain. Since ToU schedules are applied by the seller of the product, distributors can only indirectly use implicit DR through pricing agreements with sellers who then pass this through to consumers.

- Explicit DR: Supply and Demand side agree bi-lateral contracts. The terms of the contract include the expected level and timing of the response. The timing is specified as conditions that trigger the response, e.g. a specific request sent by the supply-side to the consumer, or a state of the distribution infrastructure that can be observed by the consumer. Settlement is based on the level of compliance. Because it is directly linked to the level of response, response is more reliable and therefore more valuable to the Supply-side. However, it requires substantial supervision and controls on the demand side.

III. DR OPPORTUNITIES IDENTIFIED IN AUTO-DAN

Technology-wise, for both implicit and explicit DR, the implementation of DR can be manual or automatic, or a combination of both, e.g. using augmented intelligence. The stricter terms and often shorter response times of explicit DR contracts typically requires a higher level of automation. For performance validation, and in particular for settlement of explicit DR contracts, the level of response must be quantified and measured. The response is measured relative to how much the demand-side would have bought in the case of no-DR, but this no-DR cannot be directly measured. Performance validation therefore relies heavily on forecasting methods such as those offered by the Digital Twin in Auto-DAN.

The cost of automation and advanced forecasting methods needed by the demand-side has so far limited participation by residential consumers to implicit DR only [15]. As Smart Home technology in the form of Home Management Systems such as Aeotec, HomeWhiz (by Arcelik), Apple Home etc [16], and smart appliances [17] become more wide-spread and affordable, more opportunities arise for residential consumers to participate in DR. The electrification of heat in particular, and to a lesser extent the electrification of transport, offers opportunities for residential consumers to automate their response without impacting their private lives. Finally, as a result of recent developments in the electricity markets that have led to much higher prices and potentially supply-shortages, regulators aim to stabilise prices, amongst others by promoting implicit DR for residential consumers [18, 19].

One of the main research activities for Auto-DAN project is the engagement of residential and smaller commercial consumers to engage with DR. Specifically:

i). How residential and smaller commercial consumers can be incentivised to respond, manually and/or by investing in Smart Home technology that enable suitable automated or augmented intelligence response. The research output of this work will be disseminated to regulators and policy makers.

ii). Smart Homes/Buildings technology features should be altered to make them more suitable for DR. For example, the Arcelik smart fridges that are used in Auto-DAN still require a smart plug to monitor their energy consumption, which should probably become an optional add-on to the product instead. Smart dishwashers should have the capability to schedule their cycles more in line with DR triggers, subject to constraints given by the consumer (e.g., when dishes should be washed). Heat pumps and PV inverters are already controllable but coming from an industrial background are currently not well integrated with Smart Home technology. For example, they typically use Modbus as the control protocol, which is widely used in industrial control applications, but Smart Homes use standards such as z-wave [20], Bluetooth and the new Matter standard [21,22]. The research output will be disseminated as recommendations to the various standardisation bodies in the Smart Homes industry and Smart Appliances industry, e.g., SAREF and SAREF4ENER [23,24].

The overall architecture of Auto-DAN's DR is presented in Fig.1, which includes the smart hardware infrastructure, SenseIoTy, Digital Twin and Peer2Peer Trading platform.

To achieve the Auto-DAN objectives, there are two types of DR will be implemented, one is Explicit DR and other is Implicit DR. The objective to implement the Implicit DR is to minimise the curtailment of renewable energy. The objectives to implement the explicit DR are:1). Optimized Aggregated Heating cycle 2). Optimized Aggregated MIC 3). Renewable Energy Community (REC).

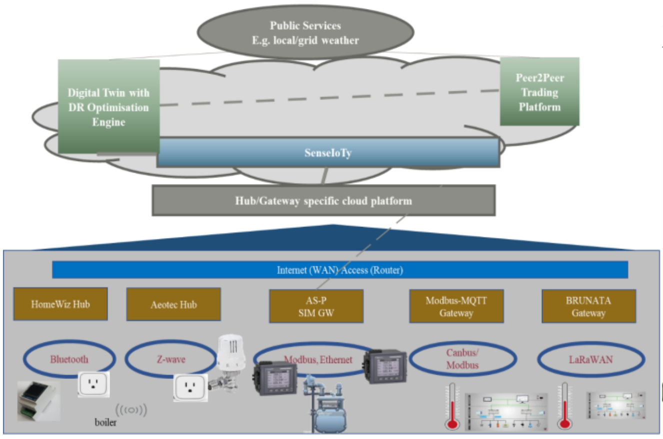

Fig.1 Architecture of Auto-DAN's Demand Response (DR).

A. Auto-DAN's Implicit DR

More expensive generators are required during times of high demand. Consequently, wholesale prices tend to track recurring demand patterns: morning (peak), day (mid-peak), evening (peak) and night (off-peak), as shown in Fig.2 [25,26]. Current retailer designed ToU schedules also follow this pattern (also shown in Fig.2). Since the more expensive generators are typically powered by fossil fuels, these ToU schedules reduce the use of fossil fuels and increase the use of renewable energy sources in the energy system, providing a societal benefit.

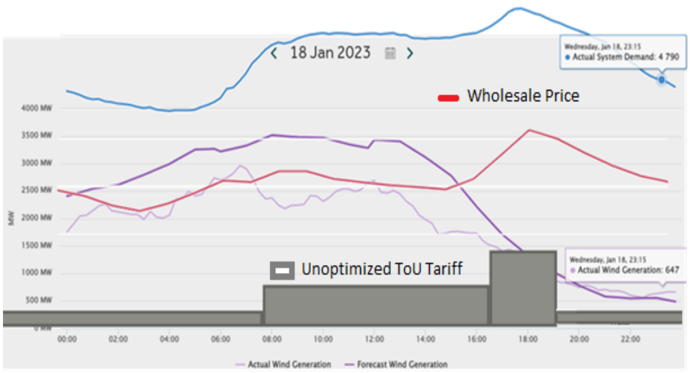

Fig.2 Wholesale prices versus ToU schedules, today [27]

1). Minimise curtailment of renewable energy

As levels of renewable energy increase, the correlation between demand patterns and wholesale prices weakens, reducing their benefits both for the retailer and society [28,29,30]. Instead, prices become more dependent on the availability of renewable energy: when the wind does not blow and/or the sun does not shine, prices will be higher. Conversely, when the wind does blow or the sun does shine, but demand is low, then it may cause an imbalance, and the wind or sun generator may have to be "curtailed" by the TSO (dispatched down) to maintain real-time supply-demand balance [31]. Auto-DAN addresses this curtailment issue by introducing a novel application of implicit DR in which the retailer-designed ToU schedules are aimed at minimizing curtailment of production from renewable energy sources due to balancing constraints. ToU Schedules are designed such that, if responded to, they increase the overall share of electricity being produced from renewable energy sources within the grid (shown in Fig.3). As such, the ToU Schedules are correlated more to the availability of renewable energy, than to the level of demand.

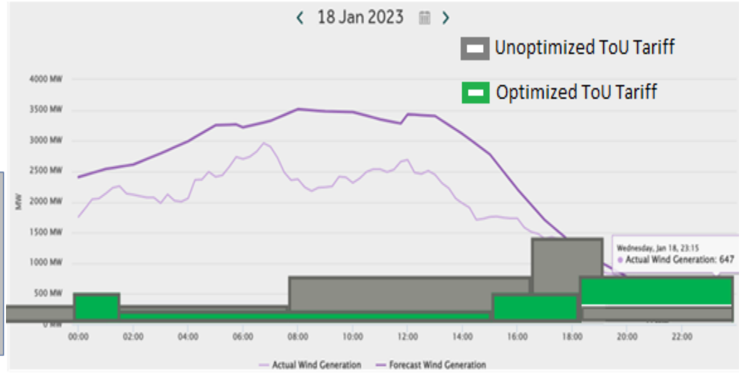

Fig.3 ToU schedule optimised to minimize the probability of curtailing renewable energy.

Since most renewable energy sources are directly related to weather conditions, the resulting ToU schedules will be more dynamic and may even change daily. There are two ways to get the response to these ToU schedules:

i). Based on the resulting ToU Schedules, Digital Twin (DT) can identify load shifting opportunities, which are then presented to the consumer on the Auto-DAN dashboard.

ii). Use the community-based Peer2Peer (CP2P) energy market, which is an experimental system to conduct research into local, community-based energy applications. It is based on community-based energy markets, typically peer-to-peer markets using micro-trades includes a simulation of the retail market, used to research how local community-based marketplaces affect retail and wholesale market designs. The simulated retail market currently uses fixed tariffs, but it can be adapted to use ToU schedules, down to 5-minute intervals. Consumers respond by buying or selling (back) energy and implementing the resulting contracts, either manually or automatically using Smart Home technology.

B. Auto-DAN's Explicit Community Demand Response (CDR)

Current applications of explicit DR target large energy systems such as national electricity grids. For it to be effective, high levels of system-wide response is required. The sheer number of residential consumers required to create such a response has led to current applications of explicit DR avoiding residential consumers and targeting larger industrial consumers instead, and smaller commercial consumers through aggregators [33]. For these consumers, terms of the explicit DR contracts can generally be stricter since they have staff that can be dedicated to the task, and often have already invested in automation. Residential consumers often cannot commit to the same terms, not just because of technology which is becoming less and less of an issue with the advent of Smart Home technology, but also because of the potential impact on their private lives [34,35]. Aggregators of DR have so far shown very little interest in developing the technologically challenging solutions that allow residential consumers to participate, e.g. by softer individual terms while achieving the same aggregated response. Auto-DAN addresses this barrier by consumers organising themselves into communities who design their own objectives such that it directly benefits their community, i.e. the objective for DR is shared by all members of the community. Rather than TSO, Retailer or DSO designed DR, the objective is self/community designed. Benefits are much more transparent for the consumers, and engagement is therefore more likely to be higher and likely to increase over time as benefits materialise. We call this innovation Community Demand Response (CDR).

All CDR applications in Auto-DAN are implemented using CP2P energy market's local, near-real-time trading marketplace for energy. Fig.4 shows the detail architecture of CP2P energy markets where every participating consumer has a dedicated software "Consumer Agent" which wholly or partly automates the trading as well as compliance with the resulting (smart) contracts through appropriate controls. The common objective of the community is represented by its own software Agent: the "Community Agent", which submits orders to the local trading market with prices aimed at eliciting the required response from the counter party in their trades. Consumer Agents optimise their own benefit, within the constraints of their capability to respond, i.e. how flexible they are in adapting their consumption, manually, automatically using Smart Appliances, or semi-automatically using augmented intelligence. A trade results in a bi-lateral contract that specifies the energy to be produced or consumed by the parties during the contract period. For Auto-DAN, the contract period is 5 minutes for electricity, 15 minutes for heat. As such, these are micro-energy trades. Response can be manual via the display or automatic using Smart Plugs and Valves. For each contract, a price is agreed between the two parties, thus making benefits quantifiable per consumer and per building, the latter by aggregating the benefits of all contracts in the same building.

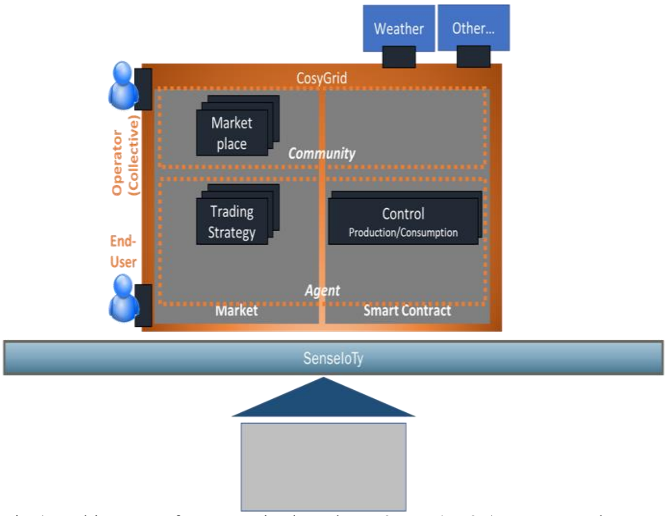

Fig.4 Architecture of Community-based Peer2Peer (CP2P) energy markets.

Every Agent has its own trading strategy which may be different from other Agents. The interaction between Agents is one of negotiation, based on each Agent's personal trading strategy. Although the level of response by consumers cannot be measured directly, the Agents commit to the orders they submit and the contracts that will be sealed as a result. The orders are based on their own forecast, generated with help from prediction engines of their own choice, such as Auto-DAN's Digital Twin. Each Agent then implements relevant controls, manual and/or automatic, for their Smart Appliances to adapt their consumption if and when required to comply as much as feasible with the contracts.

The CP2P trading marketplace allows parties to buy more and/or sell back energy prior to real-time as forecasts change or in response to prices submitted by the Community Agent or peer Consumer Agents. Consequently, the combination of orders by the various Trading Strategies, and the measured difference between contracted and actual volumes, is a reasonably accurate indicator of the level of response. The benefits of CDR are automatically distributed over the community members according to their individual level of response, as measured by their compliance with contracts. This introduces an element of competition within the community.

The following present the objective of explicit CDR implemented by CP2P trading marketplace, covering both electricity and heat:

1). Optimized Aggregated Heating cycle

In the "Heat" CDR application, the energy efficiency of a central heating system in multi-occupant buildings or estates with a central (district) heating/cooling system is improved by synchronising the heating cycles of the different consumers such that the number of heating cycles is reduced. Fig.5 shows the Optimized Aggregated Heating cycle of a central heating system using DR with three unsynchronised consumers, which minimised the heating cycles from three to one compared to non-optimized aggregated heating cycle and increase the efficiency of central heating system. A mix of manual and automated response can be used, the latter through automated valves on the radiators.

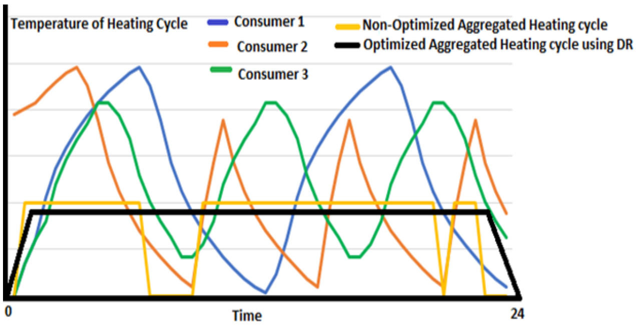

Fig.5 Optimized Aggregated Heating cycle of a central heating system with three unsynchronised consumers

2). Aggregated MIC

For capacity planning, the DSO uses a standardised statistical number to estimate the maximum power flow at a given confidence level, called the ADMD (After Demand Maximum Diversity). ADMD is used in the design of electricity distribution networks where demand is aggregated over a large number of customers. ADMD accounts for the coincident peak load a network is likely to experience over its lifetime and as such is an overestimation of typical demand. [36]. The ADMD is a number per grid connection, which multiplied by the number of (planned or actual) grid connections gives a maximum aggregated power flow at a given confidence level [37].

The MIC (Maximum Import Capacity) [38] is a charge applied by DSOs related to the maximum electrical power that the consumer agrees to import. The lower the MIC, the lower the charge since it allows the DSO to optimise capacity planning, i.e. the DSO considers this in its application of ADMD. Residential consumers currently cannot agree a MIC with the DSO: their MIC is implicitly set at the physical capacity of their connection, enforced by the main circuit breaker in the distribution panel.

Auto-DAN introduces the "Aggregated MIC" CDR application, in which the maximum power imported on a grid connection or grid segment shared by multiple consumers, e.g. multi-tenant buildings or local communities, is kept below a threshold agreed with the DSO.

Given that the MIC is specified in terms of power rather than energy, fast response is required together with very short-term forecasting. As such, automated Smart Home technology is used intensively. The CP2P energy markets implements the Aggregated MIC using a combination of two different methods:

5-minute peer-to-peer trading window. The Community Agent (acting as the Supplier) increases the price as the amount of energy already bought approaches the Aggregated MIC. As a result, the total amount of energy bought by the community will generally not exceed the MIC threshold, reducing the probability that the power during the 5 minutes exceeds the threshold. The total amount of energy bought can still exceed the MIC threshold, but the price of those contracts that causes the MIC to be exceeded will cover the penalties imposed by the DSO.

• In real-time, distributed controls together with a real-time consensus protocol between Agents, control the smart plugs and smart appliances such that the MIC threshold is not likely to be exceeded. Given that most of the time, the energy over 5 minutes will not exceed the MIC, relatively small adjustments may be needed during the 5 minutes.

• The Aggregated MIC will free up capacity in the local grid that facilitates more local electrification of heat and transport and thereby increases the share of renewable energy in the local grid. Fig.6 represents the Aggregated power, suggested MIC, and ADMD for an actual community of 12 homes.

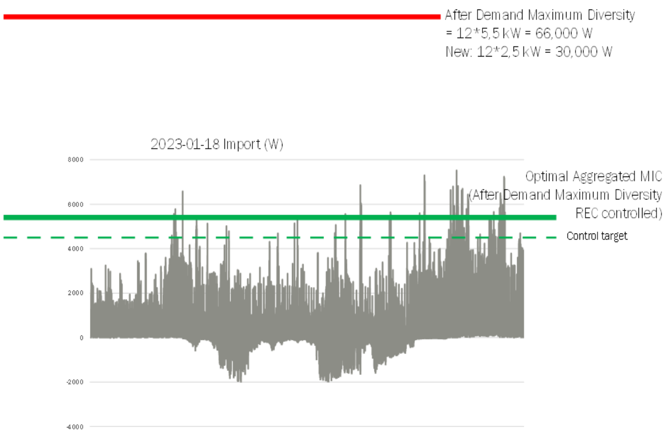

Fig.6 Aggregated power, suggested MIC, and ADMD for an actual community of 12 homes

3). Renewable Energy Community (REC)

The Renewable Energy Community (REC) is an EU regulatory concept to allow communities to benefit from renewable energy they host [39]. It is not that clear to what extent the different member states support or intend to support the REC regulation, and if supported, what benefits regulators will offer to RECs. Given that every REC must have an element of self-consumption, it can reasonably be expected that the benefits increase as self-consumption increases.

In the "REC" CDR application, self-consumption of microgeneration hosted by the community is maximised. The future price of production offered by producers or prosumers will decrease as the real-time approaches to maximise the probability that consumers will buy and adapt their consumption accordingly. Like balancing supply and demand in the grid, demand will track supply, but with REC CDR it is limited to microgeneration within a single community. Fig.7 shows the REC consumption (WsC) and solar production (WsP) in a day.

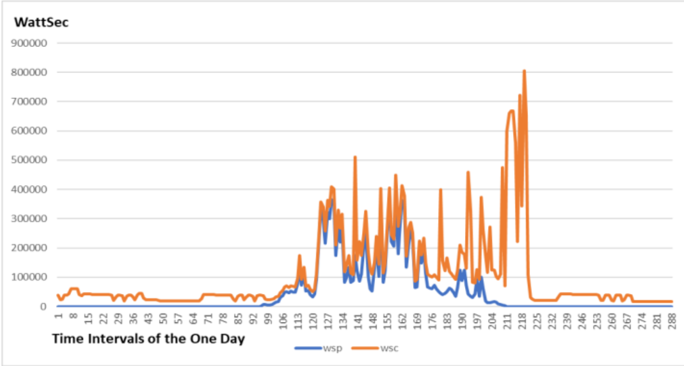

Fig.7 REC consumption (WsC) and solar production (WsP) (as opposed to import and export) in a day [40]

C. Assignment of DR to Demo sites

Here Table 3 shows the possible implementation of implicit and explicit demand response based on their objectives and technology use for different demo sites. Some demand response applications for specific objective and technology are not suitable for some demo sites. The different colour and sign convention represent the different possibilities of demand response at different demo sites. For example, for demo site 'Crannog', implicit DR with objective of minimization of the curtailment maybe possible using the Digital Twin technology, explicit DR with objective of minimization of the Aggregated MIC is not assigned for this demo site, explicit DR with objective of maximize the self-consumption of Solar PV by REC is possible using CP2P energy markets technology and explicit DR with objective of optimize the heating cycle is not applicable to this demo site since there is no central heating. The same way of interpretation is applicable for other demo sites also.

IV. Dissemination

A. Energy Performance of Buildings

Auto-DAN will make the case to regulators that, given that Building Energy Ratings credit of the buildings for installed "behind-the-meter" microgeneration [41] is considered to have a positive impact on building energy performance, the actual Energy performance of the building also depends on dynamic factors such as the behaviour of the building occupants.

Table 3. Assignment of DR and Technology use for Demo Sites.

		Implicit DR	Explicit DR		
	Objective:	Curtailment	Heat DR	Aggregated MIC	REC DR
	Technology:	Digital Twin (DT) / CP2P	CP2P (Heat)	CP2P (5 sec sampling)	CP2P + simulated PV
Sites					
Crannog		Digital Twin			
Greenogue		CP2P			
Palazzo Terragni		Digital Twin			
Medea		Digital Twin			
Student Accommodation		Digital Twin			
VideBurgos		Digital Twin			

	Not Assigned
	Assigned
	Maybe (to be investigated)
	Not possible

The Energy Performance Certificate (EPC) of individual buildings should be credited with any positive contribution by the building that increases the level of electricity produced from renewable energy within the total energy system. This includes buildings that through the dynamic behaviour of their occupants and/or Smart Appliances increase the level of renewable energy, e.g. by responding to Auto-DAN DR, whether they have their own microgeneration or not, explicit as well as implicit. These buildings should benefit from Auto-DAN's DR.

B. Local (peer-to-peer) Energy Markets

Current electricity market designs for electricity have two intertwined layers: wholesale and retail. Local trading marketplaces, with their micro-trades (potentially 5-minute trading intervals), introduce a third layer. Today, there has been very little progress in adapting market design to allow for competitive local trading markets [42,43,44].

For local trading markets to perform optimally, trading volumes must be high relative to the size of local assets underpinning the trades (load and generators). However, today's metering infrastructures, including the smart metering infrastructures being rolled out in many countries, only measure import and export. For consumers with behind-the-meter microgeneration (also known as prosumers), it forces energy markets to trade import and export rather than consumption and production. Unless the distribution of generation is heavily skewed, with none or low levels for many consumers and high levels for the remaining consumers or producers, trading volumes will be low relative to the size of local assets. Those with behind-the-meter microgeneration will then prioritise optimising against their own microgeneration, further lowering trading volumes. Such a skewed distribution is generally the case in larger markets such as the retail market but for local communities, the constraint of a heavily skewed distribution creates a high barrier for local peer-to-peer trading

Auto-DAN proposes that market designs support local energy markets through micro energy trades based on production and consumption for settlement.

A final issue with supporting local energy markets is the real-time support for micro-energy trades, not just in the wholesale marketplace but also in the metering infrastructure used by the wholesale and retail market. Advanced community applications require data to be processed in real time. Auto-Dan necessarily has its own metering infrastructure as a result, which is part of the smart hardware infrastructure, but these are not integrated with the wholesale market.

V. CONCLUSION

The aims of the Auto-DAN project are self-assessing and self-optimizing the energy performance of buildings using innovative IoT technologies. The aims will be achieved by providing five experimental services like Live Audit, optimization, Insight, Demand Response, Fault Detection to consumers within the buildings across six demo sites in three countries of Europe like Ireland, Italy, and Spain. All these services are integrated through a common IoT platform centered around SenseIoTy platform. This paper only focuses on the Demand Response services provide to the building end users. There are four specific objectives of the DR applications are identified and will be implemented to each demo sites using a combination of the community based Peer2Peer energy market platform and Digital Twin optimization engine together with the smart hardware infrastructure.

After implementing the project at demo sites, the Auto-DAN will make the case to regulator regarding the improvements required in the regulations of Energy Performance Certificate (EPC) by considering the positive contribution of the building occupant and/or Smart Appliances dynamic behaviour who increase the level of renewable energy.

Auto-DAN will also make the case to policy makers regarding the improvements required in the design of the electricity market such that, it will make the local trading markets more competitive in nature by trading the micro energy based on production and consumption instead of import and export.

ACKNOWLEDGMENT

The paper is supported by Auto-DAN: "Deploying Augmented Intelligence solutions in EU Buildings using Data Analytics, an interoperable hardware/software Architecture and a Novel self-energy assessment methodology" project funded from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 101000169.

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