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Article

Resilient Prosumer Scenario in a Changing Regulatory Environment – the UniRCon solution

Mihai Sanduleac [1]*, Irina Cironei[2], Mihaela Albu [2], Lucian Toma [1], Marta Sturzeanu [2] and Joao Martins [3]

[1] Faculty of Power Engineering, Politehnica University of Bucharest, Bucharest 060042 , Romania; m.sanduleac.ro@ieee.org
[2] Faculty of Electrical Engineering, Politehnica University of Bucharest, Bucharest 060042, Romania; albu@ieee.org
[3] FCT/UNL and UNINOVA-CTS, Lisbon, Portugal; jf.martins@fct.unl.pt
* Correspondence: m.sanduleac.ro@ieee.com; Tel.: +40-722-315-123

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Abstract: Technological developments are pushing for new solutions towards massive integration of renewable-based electricity generation in networks already facing many challenges. The paper presents a new approach for managing the energy transfer *towards* prosumers making use of a smart management of the local energy storage. The proposed grid design (including storage dimensioning procedure) is based on several operation scenarios in which the prosumer is operating as a "*load only*" entity (from grid perspective) exhibiting self-resilience and higher energy efficiency. One of the major advantages of this restriction in prosumer operation is the preservation of resilience against changing regulatory environment. This can be realized *within a newly proposed* Uni-directional Resilient Consumer *(UniRCon) architecture*. For the proof of concept three use-cases are detailed: (i) PV installations connected behind the meter, (ii) PV and storage available and controllable behind the meter and (iii) *the UniRCon architecture*. The three use-cases are then compared and assessed for *four near-future timelines* as starting points for the investment. The numerical simulations show the attractiveness of the UniRCon solution in what concerns both system operation costs and self-resilience. Savings are expressed as opportunity savings arising from difference in tariffs while charging and discharging the storage unit and due to avoidance of curtailment as well as special taxes for connection of PV (depending of regulatory environment). An extension of *UniRCon* concept is presented also at community scale, with neighbourhood energy exchange inside a cluster envisions energy supply resilience at community scale.

Keywords: storage capacity planning, regulation, prosumer; resilience; net metering; energy community

1. Background

Nowadays, electricity grids are facing multiple challenges following the high share of renewable-based electricity simultaneously promoted with dynamic evolution of the energy markets, including energy services. A valuable support is given by novel ICT-enabled solutions, which are expected to improve the overall network functionality. However, a silent player is the technological advancement with impacts on all systems levels. If not appropriately supported by existing regulatory environment, de-facto decisions will hinder large scale deployment of such solutions.

One fast-developing technology with high potential to be deployed by the energy end-users is storage [1]. National regulations consider it in a traditional way, either as load (in charging mode) or generator (in discharging mode). This requires from the storage systems to fulfil all demanding conditions for grid connection, reflected in the network codes [2], thus making the solutions more complex and expensive.

An attempt to reduce these costs is given by a close analysis of the potential interplay PV-based generation, usage and storage. The potential of photovoltaic (PV) electricity production has been already studied in scenarios considering massive deployment of PV installations, and the duck chart of California is one of the well-known case studies [3]. A simplified view of such duck-chart is provided in Figure 1.

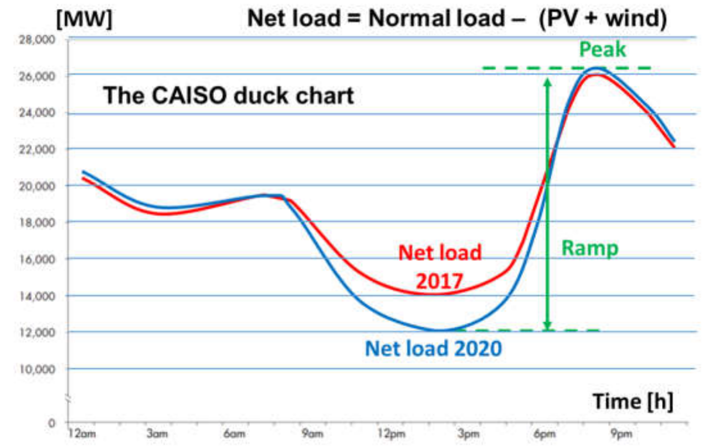

Figure 1. Californian duck curve, specific to high solar penetration. Simplified view from [3].

The studies show that, in addition to stability problems for connecting so many production units to the grid, a high solar penetration of PV-based electricity production during daytime may lead to abnormal operation conditions for all the other load following units committed for the specific day. Thus, they need to follow a net demand (load demand minus production form PVs) in the form of a duck-shape with steep ramping needs. In the example derived for a specific day (Figure 1), the power excursion associated with the net-load is showing an increase of around 220% for the interval between 20:00 to 21:00 (peak hours) compared with the time interval 12:00-16:00, when solar production was the highest in the day. Therefore, there is a need for an excessive ramp of 13 GW in only 3-4 hours. Note that this situation is far from the normal operation of most of traditional power plants. The study identifies storage as an economically viable and efficient solution to this problem. Furthermore, such situation is expected in systems with high PV penetration even in countries with high share of hydro-power generation.

For this reason, the easiest and most applied solution by DSO (Distribution System Operator) or by TSO (Transmission System Operator) is curtailment of PV power generation, with figures raising up to 50% from the PV peak power [4], [5]. Other approaches consider controlling the local energy infeed using storage as a virtual, controllable load and generator balancing facility [6]. Utilities and other stakeholders (including their customers) have to evaluate these solutions and their potential synergetic effects. Long duration energy storage (LDS) opportunities [**Error! Reference source not found.**] show great potential for high rates of return on investment when based on a combination of actions such as renewable energy self-consumption, storing energy that otherwise would be lost due to grid constraints, backup power in the event of grid failure etc.

In a growing number of countries, residential consumers have installed renewable energy sources as a measure to reduce the long-term energy costs. The European Commission gives some insight into lessons learned from national schemes on self-consumption of renewable energy and illustrates best practice in this relatively new policy area. It focuses on micro and small-scale renewable energy systems, typically with an installed electricity capacity below 500 kW [7]. The practices and characteristics of regulation that enables the cost-effective development of distributed generation to the benefit of prosumers and other customers alike are also addressed by EURELECTRIC [**Error! Reference source not found.**], based on information collected from 17 European countries [8]. The European Consumer Organization has shared their vision for developing prosumers by supporting renewable energy sources and smart devices. The vision focuses on the citizen and the quality of life in smart communities, to take benefit of the new technologies to reduce the bills, as well as to participate actively in the market to stimulate competition and support energy efficiency [9]. There are studies showing the interest of communities in increasing their collaboration for improving the community resilience of their energy ecosystems [10].

Various economical and/or technical concepts have been proposed in literature to allow integrating the new actor in the electricity industry – the prosumer – both design solutions and real-time control strategies. Integration of a consumer into various grid concepts may require appropriate communication and automatic control. In [11], a hardware architecture for a Home Energy Management system is proposed. The authors use simple concepts to show that the technology is ready to support development of the prosumer concept. A short-term decision-support models for aggregators that sell electricity to prosumers and buy back surplus electricity is proposed in [12]. The key element is that the aggregator can control flexible energy units at the prosumers. Thereby, the optimization is achieved in a consortium rather than individually. Metering prosumer's parameters is essential for implementing a real-time control. In [13], the authors promote the idea that there are two systems to measure the exchanges with the grid: a net metering system that uses a net meter to measure the balance between exports and imports and a net purchasing system that uses two meters to measure both exports and imports. The authors identify some means by which incentives are created to encourage prosumers to synchronize production and consumption.

Small-sized PV and ES systems have been recently developed for easy use in residential areas and many papers investigate the problem of finding the optimal capacities of PV and ES systems in the context of home load management in smart grids. In [14], the model explicitly considers the varying electricity price that is a result of individual load management of the customers in the market, and formulates the problem as a multi-objective optimization in a game-theoretic approach. Simulation results show that introducing PV and ES systems optimally at a customer can reduce the electricity price and hence diminish the expense of the other customers. In [15] it is demonstrated that the increasing penetration levels with variable solar power will require both short and long term prediction forecasts of the irradiance to assist the balancing of energy generation from renewables and fossil-fuel based sources, as well as conversion of irradiance forecasts into actual PV power generation readily useable by grid operators.

Another option to cope with energy control on a local rather than wide power system scope are microgrids where the energy exchange is evaluated at neighbourhood level and usually more than one energy vector is considered [16][2]. However, various control strategies have been defined as there is a large number of characteristics of the microgrid operation [17], [18]. In[19]] it is demonstrated that, order to solve the influence of uncertain PV generation on the microgrid operation, demand response (DR) and battery energy storage system (BESS) need to be introduced simultaneously by optimal scheduling algorithm.

In this paper, we propose to address, in addition to some of the previously mentioned concerns, the issue of a changing, unpredictable regulatory environment with additional constraints for local generation scenarios. The last aspect is important because curtailment policy is driven by the TSO or DSO and support schemes are driven by political decisions, both being uncontrollable factors from the point of investor in renewables, thus making the investments sustainability prone to changes which cannot be managed.

The principle of "load only" prosumer, included in all scenarios on which the planning procedure in this paper is run, has several key features: it offers a better customer resilience, an improvement in stability and predictability relevant for low voltage level (LV) network operators, and less expensive grid connection - as it is transforms a prosumer in an all-time consumer. We show that this solution, named here-on UniRCon, addresses the load-generation gap described in Figure 1 by including the cost and benefits of resilience and by converting small prosumers in entities acting as pure consumers from the AC (DSO) side. This solution is independent from any future constraints (either technical or regulatory) applied to the local generation units, thus remaining compatible with the classic design of network tailored for unidirectional energy flow.

Furthermore, this architecture can be extended to a number of energy prosumers, which can increase efficiency and resilience through the proposed UniRCon architecture at prosumer level or in a UniRCon cluster.

2. Optimal integration of renewables immune to changing regulatory environment

2.1. Introduction

Presently there are three different deployments of possible architectures for prosumers, which are presented below with pros and cons (see Figure 2):

- Prosumer V1 (Figure 2a) is a prosumer with PV (or other intermittent, RES-based generation) behind the meter, connected on the AC internal network and directly connected to the DSO grid; depending on secondary legislation, available support scheme (feed-in tariff or green certificates) might be applied either for the excess energy measured by net meter M1, or for the energy measured by the PV meter M2;
    - Advantages: support schemes apply, installed PV capacity could be greater than what is locally needed (instant power terms), which may be an advantage while good support schemes apply.
    - Disadvantages: income from support schemes is exposed to regulatory changes, curtailment asked by relevant operator may apply, especially in a high RES penetration situation.
- Prosumer V2 (Figure 2b) is a prosumer which has PV and local storage connected to the AC grid directly operated by DSO, for example for addressing local power quality issues.
    - Advantages: electricity harvested during the day can be stored and used during the evening, thus increasing self-consumption;
    - Disadvantages: each equipment is connected to the grid as generation unit, thus being exposed to network requirements and regulatory changes; curtailment is still possible, for example according to EU regulation the generator’s operation is monitored without considering prosumer behaviour; efficiency is low due to DC-from of generated electricity which need further transformation in AC – forms.
- Prosumer V3 (Figure 2c) has a device – named generically hybrid inverter - which connects PV production and storage to the AC network; it brings resiliency to the loads in islanding mode of operation after disconnecting the breaker during outages;
    - Advantages: one equipment (the hybrid inverter) is optimising the from PV and storage energy transfer, which brings better operation for both units; a good dimensioning can increase the self-consumption of locally produced energy;
    - Disadvantages: in islanding mode of operation, loads can be supplied only after breaker disconnection; the hybrid inverter needs to comply with network codes and possible curtailment orders still apply. Thus, this architecture is still prone to regulatory changes. Furthermore, the overall efficiency of PV-storage system can be improved, as DC resources such as PV and storage are still used through the AC network (lower overall efficiency due to unnecessary AC-DC-AC conversion stages).

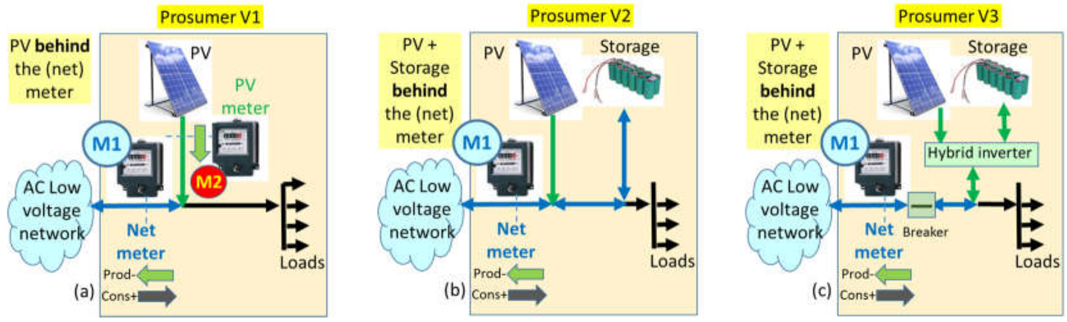

Figure 2. Usual architectures for today prosumers

None of the solutions presented above include access to a DC internal bus or allow neighbourhood energy exchange other than using the existing DSO network.

2.2. Resilient Architecture for prosumers with integrated storage.

To use as much as possible self-produced energy, a different approach is necessary. In the following a simple way of battery-size selection is illustrated, together with a simple decision logic for scheduling of battery operation. The rationale of this simple approach, instead of a proper optimization model for capacity planning, is to keep the focus on the comparison of the benefits of the proposed architecture as simple as possible, with little sacrifice on the accuracy of the model. Note however, that a sensitivity analysis is also carried out such that to prove the fairness of the comparison results.

Most of currently in-use rooftop-PV installations within Europe are in a range of 4 to 10 kW peak (kWp), depending on the roof available space and as a consequence of governmental incentives (such as feed-in tariff or green certificates) [20],[21] . Such a PV facility can generate in sunny days much higher energy per day than the household load self-consumption, the difference being injected in the distribution grid. However, following the decreasing trend of incentivized PV generation the initial over-dimensioning of the PV facility (valuable while incentives were high) is only partially compensated by local storage, if the stored energy is to be still delivered to the grid. Furthermore, curtailment of the energy delivered to the grid could be applied, and associated duck chart problem may remain unsolved. Moreover, selecting a higher level for the local storage does not solve the necessity of sending back energy to the network, as excess of energy exists by design.

The root of this situation lies in the initial planning of distributed generation unmatched with local load, following energy harvesting instead of optimal operation.

Our objective is, on the contrary, to achieve an optimal self-consumption in view of avoiding curtailment even in changing regulatory approaches like, for example, total lack of incentives for RES -based generation.

In the proposed UniRCon paradigm, PV system selection and dimensioning is based on achieving, on a daily basis, a higher energy consumption E_{Cons_day} than the local generation E_{PV_day} measured by a sub-unitary factor $K_{PV\_versus\_cons}$.

$$E_{PV\_day} < E_{Cons\_day}$$

$$E_{PV\_day} = K_{PV\_versus\_cons} * E_{Cons\_day}$$

In this approach, the UniRCon solution brings advantages to several energy actors:

- DSOs will perceive no disruptive operational changes, beyond decreased load profile: an incremental RES-based DG deployment keeps business as usual (BAU) load equivalent behaviour for all new PV owners, thus keeping grid compatible with initial design based on one-way energy flow;
- TSOs will maintain the classic control approach, with reducing effects such as duck chart ramp problem;
- Prosumer will experience:

- resiliency against network outages, due to the internal busbar which allows short to medium time operation;
- stability and predictability of the benefits brought by the RES and storage investment, thus being protected from regulatory changes related to feed-in tariffs or to curtailment policy of TSO and/or DSO;
- better self-consumption during summer time as well as high use of market opportunities during winter time, when bulk energy can be purchased at lower prices; moreover, in winter time, storage has higher availability of the capacity due to reduced PV production
- higher efficiency for the used energy, as important elements such as PV and storage are naturally functioning in DC and even many of today AC loads are also directly pluggable in appropriate DC grids, as their power supply is based on electronic technology which has initially anyhow a rectifier part which converts in DC.
- lower costs of grid-connection if consumers have the historical right to access electrical energy (a 20th century electrification paradigm).

- energy communities will especially benefit from
  - higher resiliency, achieved by design due to additional "backyard DC" network; in addition, higher efficiency of energy use could be achieved by boosting a local energy market, an embryonic model for new smart cities design;
- society will benefit from:
  - improved efficiency by energy harvesting and local use of electricity; this feature was invoked also at prosumer side, but it has a societal impact as well;
  - preserving the participation in a wide area market, like e.g. the unified European electricity market, where a significant share (40 to 60%) can be purchased from bulk production facilities;
  - paving the road to 100% renewables (already endorsed by California and Hawaii for 2045) or 100% CO_2 free energy systems (endorsed by European Union for 2050), without jeopardising stability of electricity systems;
  - minimising the cyber-security threat arising from system level control, because the end-level of UniRCon is only locally controllable.

The term of resilience has been associated to the UniRCon operation with a definition derived from two resiliency features:

- Resilience to the changing regulatory environment, which means the capability to adapt the system behaviour such that external threats such as curtailment or reduction of renewables incentives can be managed by the internal system which is stable in terms of functionalities.
- Resilience against outages and blackouts, which means the capacity to keep the prosumer operation completely unaltered by selecting its source of energy from available local resources, grid-based resources and neighbourhood resources.

With this UniRCon approach, in the next sections we present two situations: (i) a numerical example for dimensioning (capacity planning) of a PV and storage installation which is compared with a base-case of consumption in a stand-alone operation mode for the prosumer; and (ii) the opening for a neighbourhood exchange, for to further increase the local energy balance between consumption and production in a cooperative algorithm. The numerical examples do not consider special periods such as summer holidays (E_{Cons_day} very low), when auto-curtailment might be still enforced in the configuration (i) and inferred to be solved in case (ii) with UniRCons cluster acting as a UniRCon community developed in section 3 below.

Although proposed scenarios be used for dimensioning the entire system (i.e. by simultaneously optimizing the required PV generation unit, the associated storage system, and a load profile with known variability and a priori set limits of uncertainty), in this paper we will limit the analysis to a simpler problem, i.e. for existing PV installations (with known power profile and depreciation costs).

2.3. Resilient Architecture for advanced prosumers

The business-as-usual scenario is described next: let's consider a roof-mounted PV installation (1 kWp) which can produce, with variation due to latitude and season, up to 4 kWh/day during summertime, and only 1 kWh/day during the winter period. This summarizes for a 10 kWp installation up to 40 kWh energy during a summer day, significantly higher than the average daily energy consumption of about 20 kWh.

In this scenario, there is by design an excess of electricity produced locally on a major part of the year. This excess energy, if injected into the network, might lead to curtailment orders (in case of voltage limits and grid capacity violation, or even in case of stability constraints) or penalties. This scenario is also including the case when subsidies for RES and priority on renewables dispatch are cancelled. Moreover, the scenario considers an increase of self-consumption, which becomes a viable approach enforced by the situation of reaching or approaching grid parity price in many European countries (e.g. already reached in countries like Cyprus and Greece), thus collecting feed-in tariff or green certificates being less and less profitable. Therefore, sizing the generation units becomes a techno-economic problem since the profitability and internal rate of return are decisive for choosing a solution [22].

In the following we analyse the scenario of a complete self-consumption, with a grid behaviour when no locally generated electricity is injected back into the network. We are labelling this as a "no-back generation" solution, which means that even with local production, there is no AC network behaviour to show this, thus the prosumer behaves as a pure consumer on the LV network side.

To achieve the *all-time load only* behaviour we consider three different modes of network operation. The first and second situations are traditional ways of integrating PV, either directly to the grid (PV connected directly to grid through its own meter) or "behind the meter" (PV is connected to the internal bus bar on the prosumer premises). The one we propose has an additional feature, further called "resilience behind the meter" and labelled UniRCon, presented in Figure 3 and detailed below.

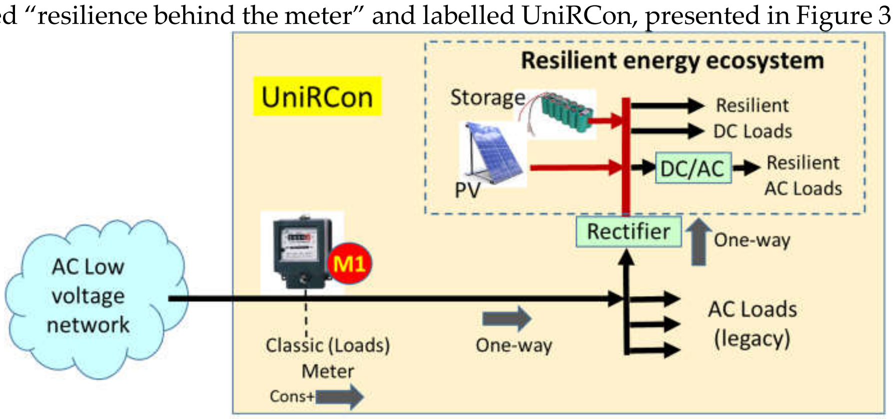

Figure 3. Renewables connected in an architecture allowing a resilient consumer behind the meter, labelled *UniRCon* (Uni-directional Resilient Consumer), with *all-time load only* behaviour on AC low voltage network

One essential aspect is that *UniRCon* is *by design unidirectional* towards the resilient energy ecosystem, which is an energy system operating independent from the DSO control, to be described in more details below. The *all-time load only* behaviour of UniRCon can be achieved with an implementation different from solutions using "zeroing-out" automation. This concept can be further extended to a cluster of prosumers, which can form a local market, as also suggested in [23].

Electricity generators connected to a local network synchronously connected to the DSO grid are separately addressed by specific network codes [2] asking for complex requirements. The *UniRCon* solution is however placed on the consumer premises and has no back generation by design. Therefore, less demanding conditions apply for the connection and operation. The need to customize the prosumer's behaviour as to allow demand response algorithms deployment is also addressed in [24] as a solution to share resources to avoid energy crisis (excessive prices).

The load-only behaviour is already implemented in some market solutions where inverters [25] are designed for microgrids operating in island mode with an architecture integrating diesel generators (gen-set) to provide the missing energy when needed by the local energy ecosystem. This gen-set can be further emulated by a network connection with load-only behaviour. In [26] a "non-export" DC microgrid is also presented for industrial and commercial sectors, pointing also reduction of interconnection fees and easier operation.

In UniRCon architecture we are focusing on residential sector and its neighbourhood, and *consider this uni-directional behaviour as a concept* for developing resilient systems, both on energy supply and on regulatory changes. The role of the common DC busbar for PV and storage connection and extensions of the concept for neighbourhood resiliency will be presented below. The UniRCon architecture offers enhanced cyber-security features, mainly due to the local relevance of the load-only behaviour of the considered system.

The proposed prosumer architecture is presented in Figure 4. We introduce the following notations in Figure 4, for describing the energy transfer at the AC-side of the prosumer -network:

P_{AC_TOT}: AC power transferred from the DSO network to the prosumer;

P_{AC_LL}: AC power to supply existing (classical) loads on prosumer' premises (internal microgrid)

P_{AC_IHM}: AC power supplied from DSO grid to the UniRCon network

Within UniRCon, the prosumer installations are acting on the principle of energy balance able to address resilience to the prosumer; therefore, we define:

P_{DC_IN}: DC available power generated at the output of the AC/DC converter

P_{AC_RESIL}: AC power available at the output of the inverter which supplies the AC subnetwork of the UniRCon.

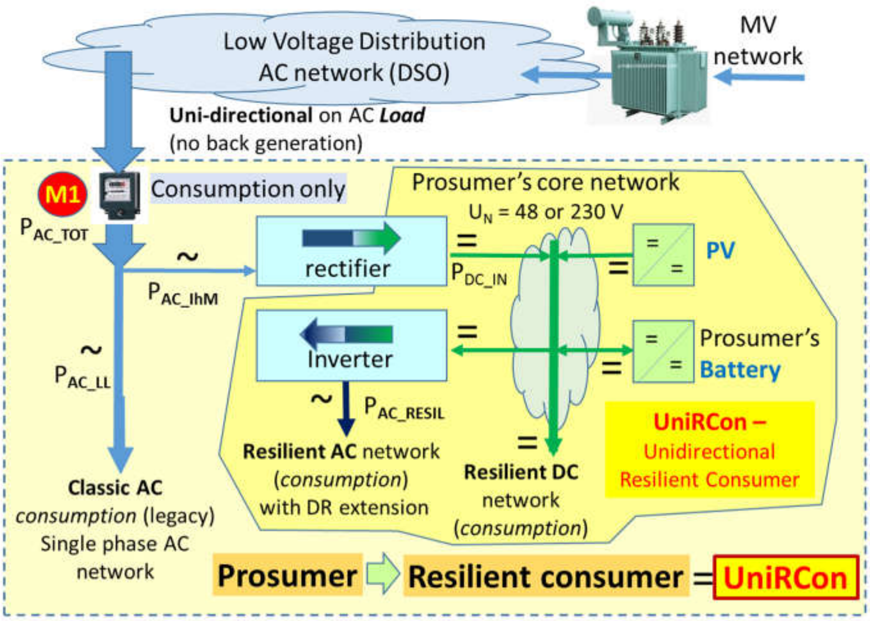

Figure 4. Proposed resilient architecture of the advanced prosumer (UniRCon)

2.2. Numerical simulation

To analyse the UniRCon architecture, we will use actual historical recorded data corresponding to typical days of PV generation coupled with a typical load curve. In the following example, we consider data associated with load characteristics of a household in Romania; the averaged profile on 14 days in October 2016 results in a daily energy consumptions of E_{DAY1} = 15.77 kWh. Based on measurements of PV production in southern Romania [27], we found typical days of electricity production with 6.32 kWh/day/kWp installed in one of the best summer days of 2016 (June 9, 2016).

Assuming a linear relationship between PV installed capacity and energy production, a 2 kWp PV installation will deliver twice as much power, i.e. 12.62 kWh/day, which is approximately 80% of the average daily consumption.

Next step is selection of the storage capacity. We consider typical days of various seasons, where the PV power production daily time series were derived from real measurements recorded every second, and averaged for the scope of this study to 15 minutes intervals. The data come from a rural site in Romania. The measurements profiles were scaled to a PV system of 2 kWp. Prosumer identity is anonymized. Figure 5 shows five typical daily of PV power production profiles, selected such that to span weather variations during an entire year: a totally sunny day (August 14) down to a very low production during cold time (November 29 in Figure 6), also partially cloudy in different seasons.

The specific production in different days has been used to simulate the entire 2016 year by combining their production in such a way that an average of 1200 kWh/kW installed PV is reached, which is usually the yearly performance for this region.

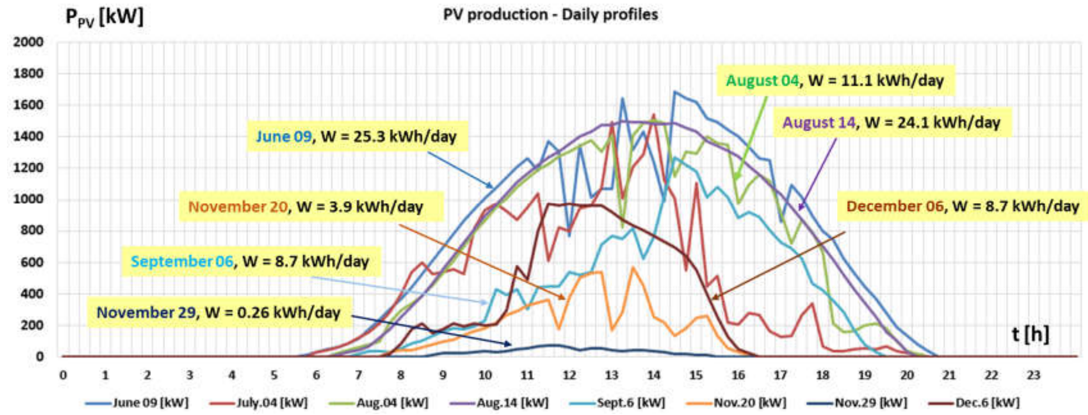

Figure 5. Electricity generation from a 2 kWp PV installation in representative days across the year

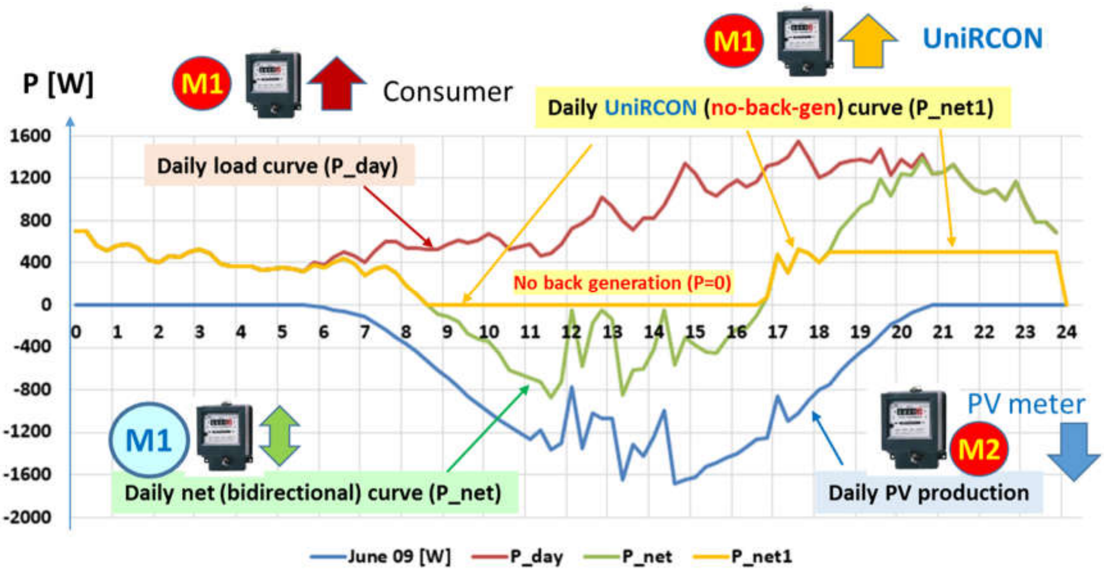

Figure 6a. Typical household electricity consumption, production and net metered energy curves for one specific day in June 2016

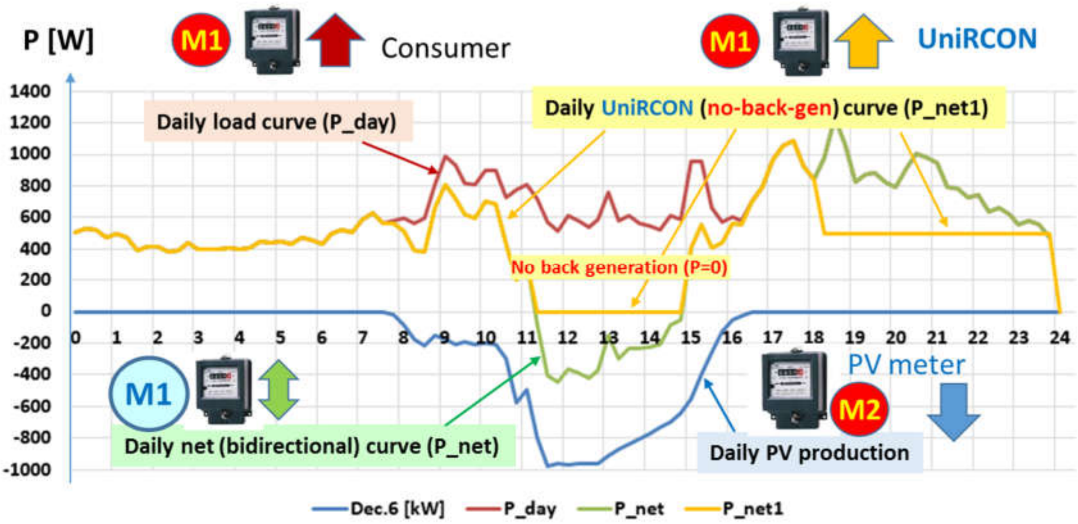

Figure 6b. Typical household electricity consumption, production and net metered energy curves for one specific day in December 2016

Figures 6a and 6b above show the load curve of a typical household in SE Europe with a total of 19.5 kWh daily consumption (P_day) in summer (fig. 6a, average in summer period) and 15.8 kWh daily consumption in winter (fig. 6b, average for winter period, superposed over the daily PV generated energy curve of 2 kWp PV-units, during two selected days from Figure 4: June 2016, Romania in fig.6a and December 2016, Romania, in fig. 6b).

To be noted that the summer typical consumption (19.5 kWh) was higher than the winter typical consumption (15.8 kWh), due to refrigerators and moderate air conditioner use, even if during winter time there is more use of lighting. The studied cases do not include electrical energy use for heating, as gas heating is available and more convenient. This can be considered a typical situation for Southern Europe, and especially for SE Europe

Figures 6a and 6b show also the daily net power exchanged with the distribution network (P_net, P_net1) in each typical day of summer and winter, for two different situations:

- The net power *P_net* defined as 15-minute average power, derived from the measurement data (active energy) of the corresponding net meter M_1; this correspond to classic net metering and to the usual reward scheme deployed with the feed-in tariff; the net-metering performed by M_1 delivers the information related to an energy which correspond to total energy transferred from the grid to the end-user;
- The net power *P_net1* is defined similarly and measured with the same net meter, however with the constraint that it describes uniquely the energy exchange between grid and the end user, i.e. seen always as a load from the grid side: the excess power produced by the PV during the day is managed by the UniRCon architecture, able to control energy transfer to and from the battery or deploying demand response algorithms.

In our test scenario, the peak-hour ramp in the evening is set with an excursion from zero to 500 W, compared to the one from -800 to +800 W (i.e. spanning 1600 W) in the net-metering situation; this means a significant reduction of the power excursion, with positive impact on mitigation the Californian duck chart situation.

Similar curves have been synthetically derived and analysed for a number of representative days and have been assessed in terms of savings and resilience in different scenarios, which correspond to near future timelines of year 2018, 2020, 2022 and 2025.

To assess the 4 scenarios, market environment has been modelled as well, by highlighting and valuing cost dynamics and technology trends for PV and storage related equipment, and curtailment.

Assumptions and constraints for the proposed model for assessing the cost-benefit comparison between the three use-cases are summarized below.

- A bottom-up approach is used, where a decision-logic was used for the daily scheduling (time of charge and discharge and amount of energy to be charged/discharged) of the battery. This scheduling module is based on perfect knowledge information from past recorded data (PV power production and load demand). Note however, that this approach does not affect the economic/technical calculations below. They indeed may influence a real-time operation of the system. The decision logic used for scheduling the battery is give in Figure 7, below:

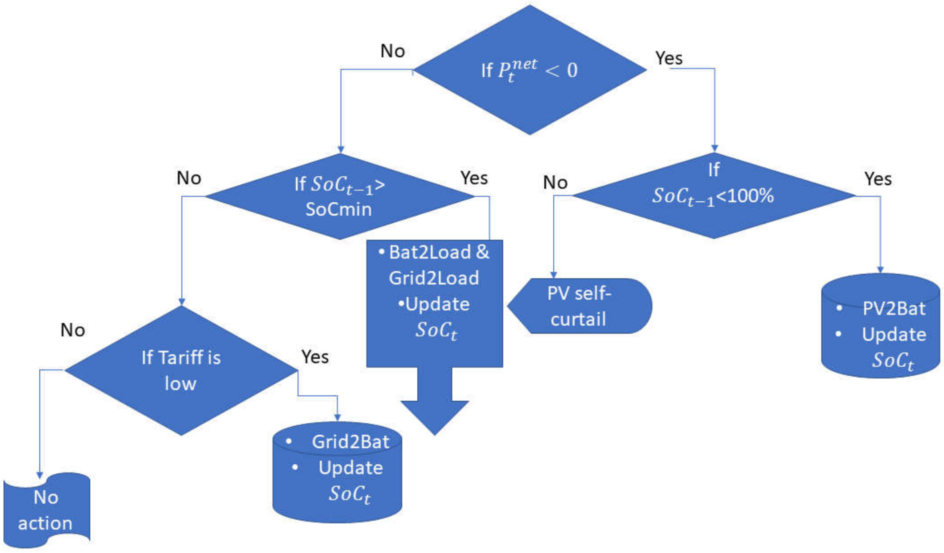

Figure 7: Decision logic for scheduling the battery operation under a predefined capacity of the battery.

- For the simplicity of calculations, we have limit the number of daily cycles of the battery to 1, where the cycle is counted as full charge and discharge. This approach helps to relate all cost calculations to a daily basis approach. Note that partial charges and discharges are allowed within the day if their cumulative effect do not exceed a full cycle. This constraint is reflected in the fixed cost associated with battery utilization for each kWh of stored energy, as it is defined in equation (11) from the Table 1 below. This cost is a simplification of a LCOE for the BSS and could be interpreted as an estimate for the average share of the total investment and installation cost of the BSS to the amount of energy stored/released within a cycle of use.

The rest of the calculations are based on a daily reference and they are summarized in Table 1, below.

Table 1. Mathematical model for the comparative calculations

(1)	$E^{load} = \int_{t=0}^{T} P_t^{load} \cdot \delta t \equiv \Sigma_{t=0}^{T} P_t^{load} \cdot \Delta t$	E^{load} is the total energy needed during the day to supply the total aggregated loads of the prosumer, in (kWh) P_t^{load}, is the average measured power consumption within the time step, in (kW) Δt=0.25 is a ratio equivalent with 15′ time interval recordings

		T=24 (h) is the time interval for a day in hours.
(2)	$E^{PV} = \int_{t=0}^{T} P_t^{PV} \cdot \delta t \equiv \Sigma_{t=0}^{T} P_t^{PV} \cdot \Delta t$	E^{PV} is the total energy produced by the PV installation during the day, in (kWh)
(3)	$P_t^{net} = -(P_t^{load} - P_t^{PV}) \ \forall t \in \{0..T\}$	P_t^{net} is the net-metering power balance (for each time interval $\delta t = 15'$), in (kW)
(4)	$E_{nec}^{bat} = \int_{t=0}^{T} P_t^{net} \cdot \delta t \equiv \Sigma_{t=0}^{T} P_t^{net} \cdot \Delta t$	E_{nec}^{bat} is the estimated value of daily energy necessary to be stored by the BSS (BSS capacity for UniRCon), in (kWh)
(5)	$E^{PV2grid} = \begin{cases} E_{nec}^{bat}, \ if\ En_{nec}^{bat} < SoC^{MAX} \\ SoC^{MAX}, if\ En_{nec}^{bat} > SoC^{MAX} \end{cases}$	$E^{PV2grid}$ is the energy to be sent back to the grid, in (kWh) SoC^{MAX} is the maximum allowable state of charge of the BSS, in (kWh)
(6)	$E_{self}^{PV} = (E^{PV} - E^{PV2grid}) \cdot \eta_{\mathrm{TECHNx}}$ (kWh)	E_{self}^{PV} is the portion of PV power production that is used locally (self--consumption), in (kWh) η_{TECHNx} is the average efficiency of the inverter (constant value was considered instead of an actual function of power transfer)
(7)	$E_{used}^{DSO} = E^{load} - E_{self}^{PV}$	The amount of energy coming from the DSO, in (kWh)
(8)	$C_{E_{load}}^{DSO} = Cost^{DSO} \cdot E^{load}$	Total daily cost of the energy if all loads are supplied with energy from the DSO, in (€). $Cost^{DSO}$ is the unit cost of energy purchased from the DSO, in (€/kWh)
(9)	$C_{E_{used}}^{DSO} = Cost^{DSO} \cdot E_{used}^{DSO}$	Total daily cost of the energy purchased from the DSO, in (€)
(10)	$C_{day}^{PV} = P_{nominal}^{PV} \cdot \frac{C_{perInstalledkWp}^{PV}}{N_{H_{year}} \cdot N_{years}} \cdot 24$	C_{day}^{PV} is the estimated fixed daily cost for the PV system, in (€) $P_{nominal}^{PV}$ (kW) is the installed PV capacity $C_{perInstalledkWp}^{PV}$ is the fixed cost per unit of kWh of PV produced energy (€/kWh) $N_{H_{year}}$ is the total number of hours within a year (h/year) N_{years} total number of years in the simulation (years)
(11)	$C_{day}^{bat} = (E_{nec4PV}^{bat} + E_{resil}^{bat}) \cdot \frac{C_{perInstalledkWh}^{bat}}{N_{cylces}}$	C_{day}^{bat} is the estimated fixed daily cost for the BSS, in (€)

		E^{bat}_{nec4PV} is the battery installed energy necessary for increasing PV-self consumption, in (kWh) E^{bat}_{resil} is the installed energy required for resilience, in (kWh) $C^{bat}_{perInstalledkWh}$ is the fixed cost per unit of kWh of battery storage, in (€/kWh) N_{cylces} total number of guaranteed cycles for the respective BSS technology, in (p.u.)
(12)	$Sav^{en}_{cheap} = E^{bat}_{buy_{cheap}} \cdot \Delta Cost^{DSO} \cdot k_M$	Sav^{en}_{cheap} are opportunity savings when using the battery to buy energy from the grid when it is cheap and use it when it is expensive, in (€) $E^{bat}_{buy_{cheap}}$ amount of energy purchased at cheap prices from DSO and stored in the battery for later use, in (kWh) $\Delta Cost^{DSO}$ difference in tariffs (e.g. day-night or real-market prices), in (€/kWh) k_M coefficient capturing the market opening for opportunities (p.u)
(13)	$Sav^{en}_{sold}=E^{PV2grid} \cdot (1 - k_{curtail})$	Sav^{en}_{sold} is the savings for sold energy $k_{curtail}$ curtailment factor for PV excess energy to be sent in the grid in (%)
(14)	$C^{prosumer}_{en} = C^{DSO}_{E_{used}} + C^{PV}_{day} + C^{bat}_{day} + C^{bat}_{loss} + C^{COMM} - Sav^{en}_{cheap} - Sav^{en}_{sold}$	$C^{prosumer}_{en}$ is the total cost of prosumer used energy, in (€) C^{bat}_{loss} are the cost for the lost energy due to charge/discharge cycles and other aging factors for the BSS, in (€) C^{COMM} is the daily cost for communication, in (€)
(15)	$Resilience^{UniRCon}_{Day} = \frac{E^{bat}_{supl}}{\frac{E^{load}}{24}} \cdot 60$	Period of resilience in minutes, based on the supplementary energy in battery, kept only for resilience situations
(16)	$Savings_k = \frac{C^{DSO}_{E_{load}} - C^{prosumer}_{en}}{C^{DSO}_{E_{load}}}$	$Savings_k$ are the relative savings in the UniRcon architecture, in (%) from the total cost if all energy would be purchased from the grid

In equations (1) -(16), the daily consumed energy, (E^{load}) and the PV produced energy (E^{PV}) are calculated based on constant average powers on a certain interval (Δt), which is in our case of 15 minutes. The power at the level of utility net meter (P^{net}) is calculated with (3). For our no-back-generation solution, we consider that the necessary energy for a battery is the time integral of active power which may be injected back in the network, if no storage is present behind the meter (E_{nec}^{bat}). However, if a behind the meter battery with the capacity of SoC^{MAX} is available, then the energy which may be effectively sent back in the grid is $E^{PV2grid}$ shown in (5). Due to conversion efficiencies, we simplify the formula in (6) describing the PV energy used locally as being affected by the efficiency of inverters and DC-DC converters, which is higher in hybrid networks rather than in pure AC networks (η_{TECHNx}, with x=1 for hybrid inverters and 2 for the internal DC bus in the hybrid micro-grid). The need for remaining energy, to be purchased through DSO grid is E_{used}^{DSO} from (7).

The cost-benefit analysis derived from the quantities above is described by $C_{E\_DSO\_CONS\_100\%}$, the cost of energy supplied through the external (DSO) network in case of a classic consumer behaviour (scenario 1) and $C_{E\_Supplier}$, the cost of energy in case when only the remaining E_{DSO_USED} energy needs to be purchased. All costs are considering also VAT. Daily costs for using PV and battery are presented in (10) and (11) and are based on a simplified approach related to return of investment in N_{years} for PV and N_{cycles} for battery. The simulation also considers additional aspects, such as the price of monthly communication C_{COMM} in order to allow the transmission of curtailment signal – if this is an operational need; $C_{PV_{kW_{inst}}}$ is the price for kW of installed power; E_{INST_RESIL} is the additional battery energy installed only for resilience; $E_{INST_{BAT}}$ capacity is used for storing PV energy or cheap energy from the AC grid; Sav_{Cheap_En} represent the savings due to buying energy when it is cheap (having the kWh cost $C_{kWh_{Supplier_{cheap}}}$ instead of standard kWh cost $C_{kWh\_Supplier}$ obtained from the current supplier), being stored for later consumption.

Numerical simulation considers revenues (or savings) obtained from buying cheap energy from energy market using DSO network, by engaging PV unused battery capacity (12) with a market opportunity factor K_M and for the feed-in tariff of the PV energy sent back in the grid Sav_{SOLD_En}, quantities which are both affected by curtailment factors (13).

Finally, daily costs for a prosumer are sum-up with (13); it is considered the energy losses in batteries and the cost of buying cheap energy during low PV-generation (e.g. in winter), and using the same storage set-up (batteries) as for the case above, now partially or totally unused.

The daily savings are given by the difference between cost of energy supplied only from DSO, without any local investment (user which is not prosumer at all, but just regular consumer) – relation 8 below and the daily costs of its prosumer costs. Relation (19) gives relative values if these savings, compared with traditional costs of energy obtained from DSO. Negative values show an un-profitable investment and positive ones show level of profitability for a number of years (10 years proposed in table 1a and 1b). This saving KPI is used to compare use-cases in different timelines (horizons).

Table 2. below include the input conditions which have been chosen for calculating the economic aspects, to enable the comparison between the three use-cases. The horisons 1, 2, 3, and 4 correspond to expectations in years 2018, 2020, 2022 and 2025.

Table 2. Technical and economic input data for later comparison between three use-cases (RES behind the meter, RES + storage behind the meter and UniRCon)

No.	Abbreviation	Description	Horison 1	Horison 2	Horison 3	Horison 4	Unit
1	$C_{Investment}^{bat}$	cost of battery investment	700	600	500	400	Euro/kWh installed
2	N_{Cycles}	number of battery cycles per lifetime	7000	7000	7000	7000	Cycles / lifetime

3	C_{day}^{bat}	Specific cost of the service to store energy in BSS – Storage as a service SaaS [Euro/kWh]	0.100	0.080	0.063	0.044	Euro/kWh SaaS
4	$Cost^{DSO}$	Electricity tariff (flat) for purchasing the energy from the grid [Euro/kWh]	0.120	0.130	0.140	0.150	Euro/kWh
5	$Cost^{DSO} - \Delta Cost^{DSO}$	minimum tariff used for the energy supplied to the loads [Euro/kWh];	0.060	0.065	0.070	0.075	Euro/kWh
6	K_M	the market opportunity factor for buying cheap(er) energy [%];	20%	40%	60%	80%	[%]
7	$\mathrm{Cost}_{sold}^{\mathrm{DSO}}$	tariff used to buy-back the injected energy into the distribution network (feed-in tariff) [Euro/kWh];	0.080	0.060	0.040	0.020	Euro/kWh
8	η_{bat}	Overall efficiency of the batteries [%];	90%	91%	93%	95%	[%]
9	$K_{curtail}$	curtailment factor for PV excess energy to be sent in the grid [%];	0.00%	10.00%	15%	25.00%	[%]
10	$C_{Investment}^{PV}$	cost of PV for each installed kW, uniRCon solution [Euro/kW] ;	1500	1200	900	600	Euro/kW
11	$C_{InvestmentClassic}^{PV}$	Cost/kW_PV+Pwr.El+install, classic solution	1800	1400	1100	800	Euro/kWh
12	$N_{H\,years}$	number of PV hours per year (at PV nominal power)	1200	1200	1200	1200	Hours / year
13	N_{years}	number of years for PV and Electric Power investment return;	15	15	15	15	Years
14	$C_{UniRCon}^{PV}$	Cost of kWh produced, PV with UniRCon	0.083	0.06	0.050	0.0325	Euro/kWh produced
15	$C_{Classic}^{PV}$	Cost of kWh produced, PV classic	0.100	0.078	0.061	0.044	Euro/kWh produced
16	E_{resil}^{bat}	Battery energy used only for resilience [kWh];	0.060	0.165	0.220	0.325	kWh

17	$Resilience_{AC\_Genxit}$	Resilience [minutes] with UniRCon, based on E_{BAT_RESIL}	4	12	16	24	Minutes
18	$Resilience_{Day\_UniRCon}$	Resilience, [%] per day with UniRCon	0.3%	0.8%	1.1%	1.7%	[%]
19	η_1	efficiency of PV-BSS in classic option 1 [%]	86.0%	87.0%	88.0%	89.0%	[%]
20	η_2	efficiency of PV-BSS for the UniRCon option [%]	91.0%	92.0%	93%	94.0%	[%]
21	Year	Scenarios run for the respective year	2018	2020	2022	2025	Year
22	C_{RESIL_Day}	DSO daily tariff for providing increased resilience	0.05	0.1	0.1	0.1	Euro/day

Some details about the meaning of different rows are given below:

- cost of energy ($Cost^{DSO}$) in line 4 includes VAT (this value may vary between countries, and used values have been considered for Romania, where energy today is still cheap, at around 12c/kWh, including VAT).
- Line 5 gives input values for cheaper energy obtained from the AC grid based on opportunities ($Cost^{DSO} - \Delta Cost^{DSO}$). It is considered a mix between e.g. night tariff and near real-time opportunities, e.g. so called negative prices when renewable energy is in excess for short periods such as one-two hours.
- Line 6 tries to model the evolution of energy markets, which initially does not consider well the opportunities for cheap energy, because mechanisms on exploiting such opportunities need an evolution; as an example, situations with very low or negative prices due to excess of renewables need near real-time ICT chains and proper market functionality. Also, multi-tariff solutions (e.g. time of use tariff) need smart metering rollout and this is also a matter of penetration over time. For addressing the evolution of being able to use all the energy market cost reduction opportunities (including flexible tariffs) is described by a "market opportunity factor", which evolves in our model of calculation from small use of opportunities (20%) to high use of opportunities (80%).
- Line 7 is modelling the reduction in time of the feed-in tariff or of green certificates, one of the main reasons for considering the new solutions with storage behind the meter.
- Lines 10 and 11 represent assumptions for the price of equipment, in an AC connected, grid code compliant situation and in an independent DC grid, not synchronous with DSO's AC network; as it is difficult to bring real prices even for today situation (different estimations or market prices being in a range from 1 to 2, we took two scenarios, one which is more optimistic (a) and one which is more classic (b), which may include also variations from country to country for accommodating the equipment which includes cost of the installation. We show later that we obtain that for both assumptions a similar ranking for the use-cases of the numerical simulations.
- Line 12 assumes an equivalent of 1200 hours of maximum power of the PV installation, which is usual for Romanian territory (usually 1200 to 1350 hours over the country) [**Error! Reference source not found.**] and which can be even bigger for southern Europe (Greece and Spain have places with 1300-1600 hours equivalent). The number has been considered

the same for all horizons (2018, 2020, 2022, 2025), but may increase if the PV technology becomes better (we did not consider this option, even if this may be possible with higher efficiency of next generation PV panels);

- Line 13 is the time for financial analysis, which has been simplified in this model for all use-cases, without interest or other aspects of a LCOE calculation, considering e.g. that the financing is eventually free, due to a support scheme. A real LCOE calculation may show lower benefits for all compared use-cases, however to be noted that this does not affect the ranking. A deeper study can be made to capture better the financial aspects. However, the scope of this work is rather focused on the technical architectures that do not change a financial ranking of projects financing.
- Line 18 gives an image of the resilience factor, meaning how much of a full day can the prosumer continue its activity without grid energy (outage or blackout)
- Lines 19 and 20 gives estimated efficiency for AC-connected PV and storage resources (line 19) and for the DC-connected resources and loads (line 20), as a simplified way to bring in the model the total efficiency in both cases.
- Line 21 gives the starting point of the financial analysis.
- Line 22 proposes a daily tariff asked by DSO in order to increase the resilience of the supply of the prosumer, in traditional situation, without UniRCon solution; the value has been chosen at low level (maximum 0.1 Euros/day in the last horisons, meaning only 3 Euros/month), but this aspect makes more fair the comparison with the UniRCon solutions.

The assessment shows that, for each of the scenarios, there are three different use-cases:

1. The use-case labelled *UC1-NM* is considering the net-metering operation in the existing way, with PV installations behind the meter and no storage on prosumer's grid side;
2. The use-case labelled *UC2-NM+Stor* is treating the same case of net-metering operation, with PV behind the meter but additionally 2 kWh energy storage in the prosumer installations (behind the meter), in order to enable a local use of the PV-produced energy;
3. The use-case labelled *UC3-UniRCon* corresponding to a so-called no back generation situation, where the prosumer has only consumption on grid side, but uses PV production and internal storage as enabling local energy use together with self-resilience feature; the use-case considers 2 kWh of local energy storage, in order to compare with the second use case (three and four kWh of storage have been also analysed but they are relevant for expansions in future work).

The structure of the internal grid for the three use-cases are presented, for more clarity, in Figure 6 below:

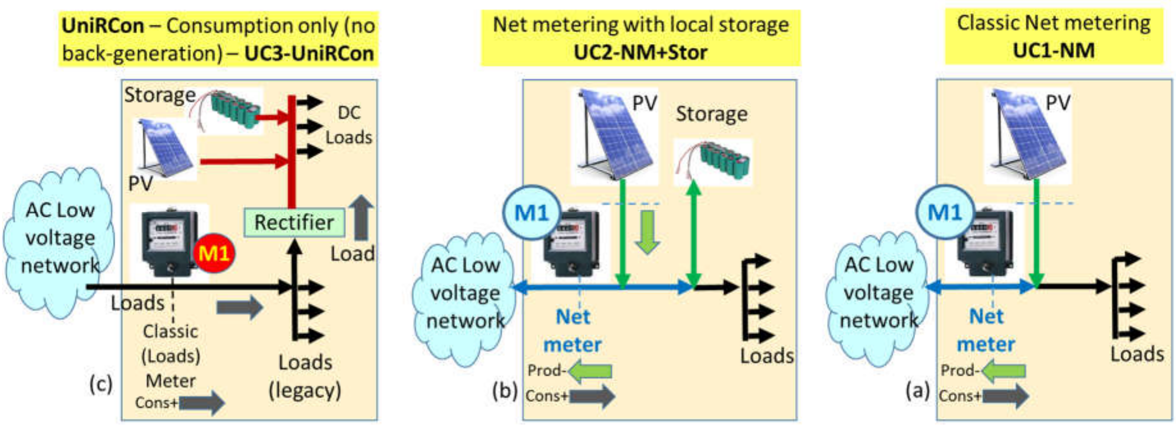

Figure 8. Internal resources of the prosumer in the three use-cases.

It can be observed that in all situations we have only one meter placed on the common coupling point with the grid. In first tow situations it is a net-meter, as energy can still be injected in the grid, but in the third situation (UniRCon) we can use a classic meter for loads only (legacy meter), and the other direction energy measurement can be only used by DSO to be proved that it has always a consumption-only behaviour.

Figure 9a presents results from the considered example, showing the cost savings from each of the use-cases for all four timelines. It is a simplified comparison among the costs of investment and energy costs in three use-cases and 4 horizons. The "negative savings" show that on a total life basis (in line 14 of the tables above we selected 15 years), the investments are not covered during this time period and bring in fact losses (energy cost savings are lower than investment and operational costs). The positive values show that the simplified calculation show savings in energy use (energy cost savings are higher than investment and operational costs). In the figure, in the model with no subsidies, only UniRCon solution does not bring negative results in the 2018 horison. The classic net-metering with or without storage suggest need for subsidies if the investment is made in horison 1 (2018, bars in blue) and only the Table 1 conditions of horizon 2 to 4 (2020, 2022, 2015, bars in red, green and magenta) give savings of the investment.

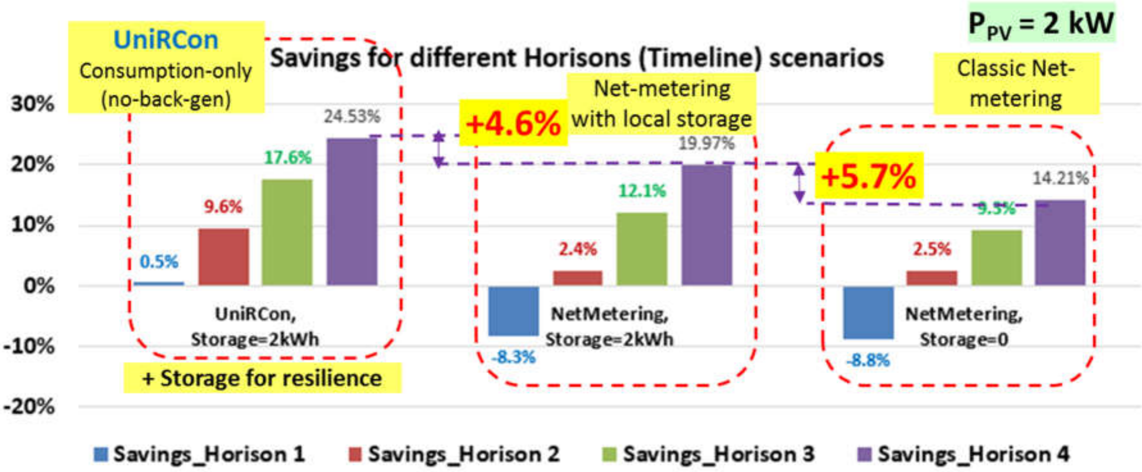

Figure 9a. Cost savings (example) comparison for the three use cases: net metering with or without storage and UniRCon (no-back-generation) solution –investment costs based on table 1

Figure 9b shows the cost savings from each of the use-cases for all four timelines by taking into consideration also a DSO tariff for increased resilience (0.1 Euro/day in horizon 2-4, as per Table 1). The savings of UniRcon solution are in this situation 8.4% compared with 4.6% in previous solution, thus showing a high attraction towards UniRCon compared with resilience measures taken by the DSO in its grid and compensated by a resilience small monthly tariff (or fee) of only 3 Euros, as being 4 to 5% of the bill for energy taken from the grid. To be noted that still the increased resilience which can be provided by the DSO is in terms of increased supply time and decreased number of interruption, but does not fully comply with the UniRCon immunity (no interruption at all) and resilience (survival on excess storage, space for further measures taken to increase time of resilience, by changing consumption priorities).

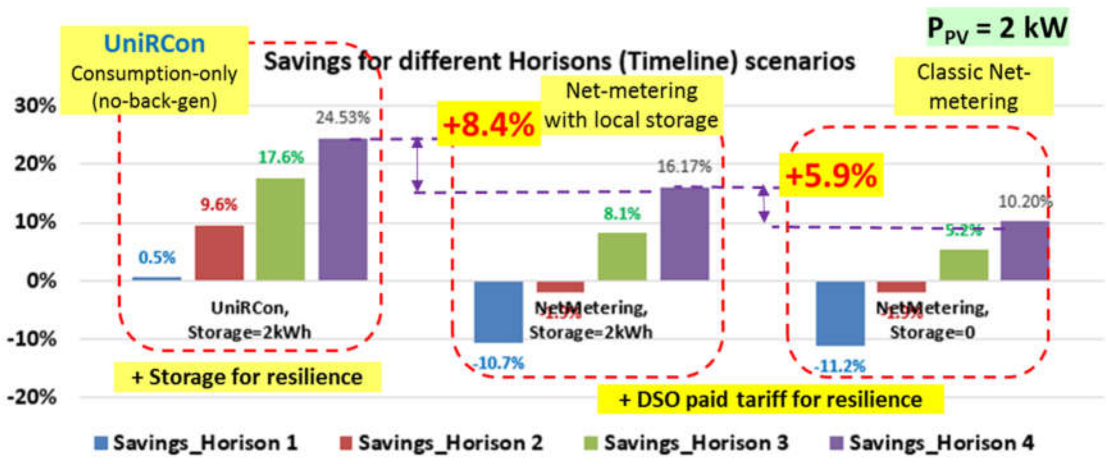

Figure 9b. Cost savings (example) comparison for the three use cases: net metering with or without storage and UniRCon (no-back-generation) solution –investment costs based on table 1 and DSO tariff for resilience

To be noted that in the *UniRCon* no-back-generation situation, additional storage is considered for supporting resilience during power outages, which is increasing from year 2018 up to year 2025 timelines, with corresponding additional costs. The storage used for resilience is chosen in such a way that it brings for the 2018 horizon an average of 5 minutes of self-resilience – sufficient to pass short time, up to 30 minutes of self-resilience in year 2025, when storage technology is expected to be much cheaper than today. Cheaper storage may improve even more the resilient behaviour.

The scenario described above is derived from a daily average consumption of a selected residential point having E_{CONS}(day)=15.8 kWh, with P_{PV}=2 kWp, and by treating the consumption and production versus storage in all use cases for typical days from figure 4, with daily electricity production of 12.6 kWh, 7.54 kWh, 4.36 kWh and 0.26 kWh respectively (covering all seasons production expectancy); this corresponds to an operation of 1200 h/year at rated PV peak power.

- In the specific case which has been studied, we have higher cost savings in the no-back-generation situation (use case *UC3-UniRCon*) comparing with the classic net-metering of PV with or without storage behind the meter (+4.6% compared with UC2-NM+Stor, which also bring 5.7% more savings compared with classic net-metering without storage UC1-NM). The percentage values correspond to the cost of power electronics installations related to PV and storage, as presented in tables 1, showing that even on a different cost scenario, UniRCon remains a slightly better savings favourite, while advantages related to resilience to grid outages as well as to changes in regulations are better than the classic use-cases (PV and PV+Storage behind the meter).
- If the DSO introduces a tariff for increasing resilience (longer period of delivery, smaller number of interruptions), the difference in UniRCon savings compared with the storage behind the meter increases to 4.8%, suggesting that it is better to invest in local immunity / resilience to mitigate DSO interruptions; it is also possible that a 0.1 Euro./day for increasing DSO resilience (which is only around 4 to 5% of the energy bill if this is purchased from the DSO grid) may not bring similar results at DSO level, because of the legacy AC design of the grid, which may need more complicate and expensive measures such as microgrid technologies, including grid-based storage.

The analysis suggests also that the self-resilience *by design* may reduce in the future also the constraints for DSO power quality in terms of KPIs such as SAIDI or SAIFI, thus creating room for new approach of the distribution supplying resilient entities.

3. Expanding the architecture towards community-level energy exchange

In the previous section, it has been shown that UniRCon solution has several advantages over the traditional integration of renewables, also when electricity storage is considered. Although details regarding extension of the UniRCon concept to community level will be presented in further work, we present here only the concept.

In the individual solution shaped in section 2, the UniRCon operation as always-a-load (from DSO side) has been enabled by considering the PV production (or other specific DER) is always the source of the excess of energy production versus consumption including storage and by such is always ensuring a no-back-generation mode.

However, in energy communities, either neighbours within buildings or small districts or in villages, some energy actors may be not in the position to have their own production. Therefore one can build on local collaboration strategies, still keeping a no-back-generation to the traditional AC grid. By exchanging energy in the neighbourhoods with resilience against power outages as main goal, the UniRCon architecture can be expanded. Figure 10 introduces the added module for exchanging DC based energy through a common DC bus at neighbourhood level. The DC-DC module, which depicted in a dark green, allows exchange of energy between the local resilient bus and the neighbourhood common DC bus.

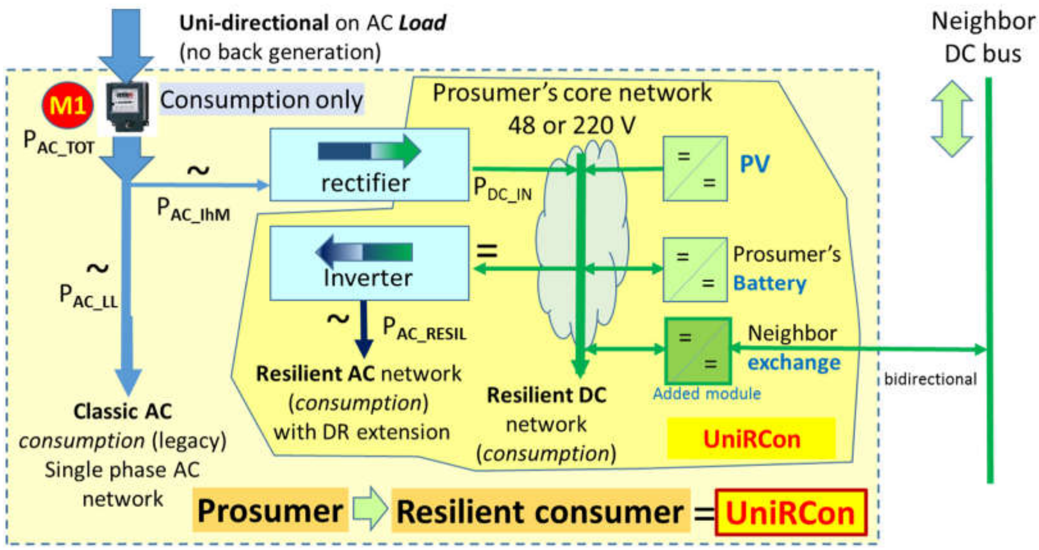

Figure 10. Extension of the resilient architecture of the prosumer

Figure 11 extends the view into the neighbourhood and shows the exchange between neighbours as resilient prosumers or consumers.

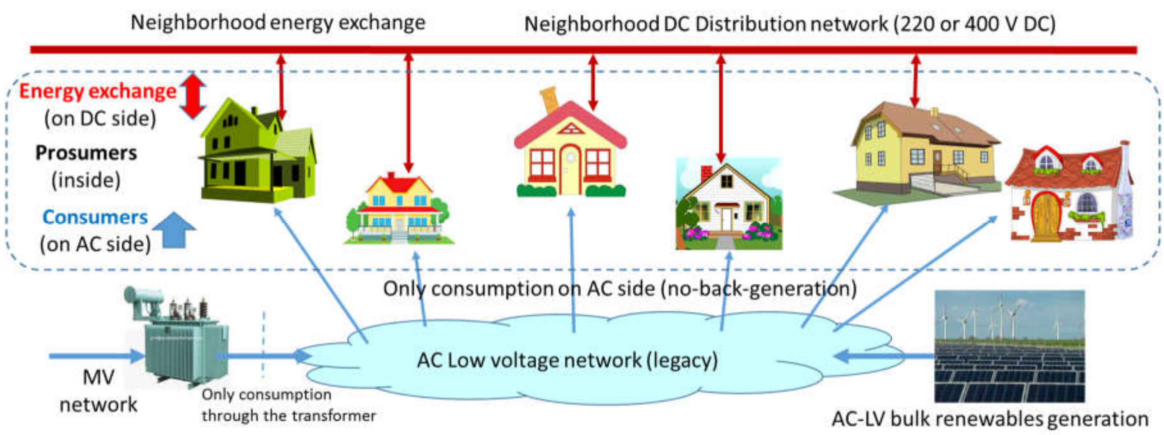

Figure 11. Extension in the neighbourhood energy exchange

It is expected that *UniRCon* extension will bring all advantages already presented for the single prosumer architecture: high resilience and increased efficiency, business as usual on AC distribution network.

Figure 12 shows the *UniRCon* cluster obtained by aggregating all *UniRCons* with an equivalent consumption C1 – without any generator connected to the grid, and all the other consumers can be aggregated in C2. With adequate implementation, *UniRCon* equivalent can be introduced allowing a significant reduction of model complexity which is further enabling improvement of grid operation.

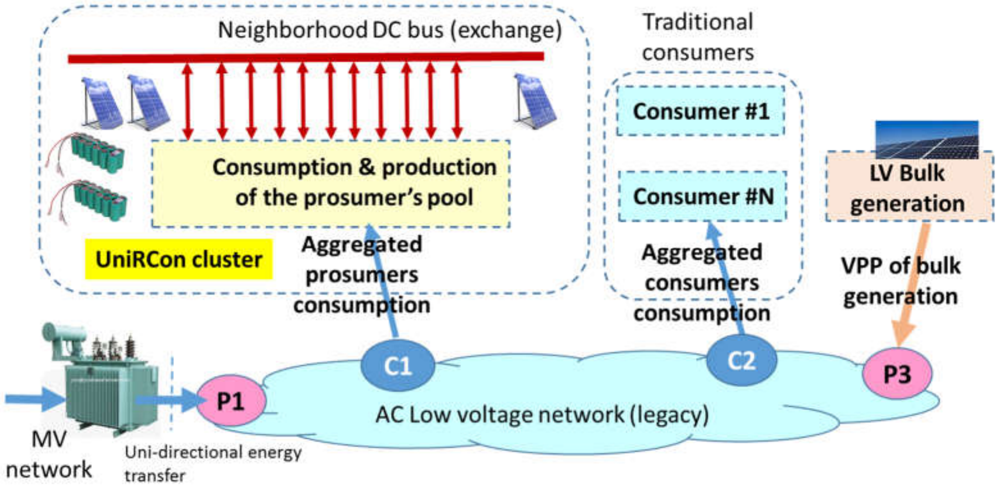

Figure 12. Operation with increased network security by having a reduced number of energy injection points in the network

A good design in dimensioning *UniRCon* internal generation + storage resources allows to keep it as an equivalent consumer - which is a good situation for the DSO claiming for the "business as usual" for his distribution grid. Moreover, if the DSO allowances for connecting bulk generation keep a good balance with the LV network consumption, the MV/LV transformer may be kept as well in a uni-directional flow of energy. Such strategies are relevant for win-win situations, as the network operation enables stability and the prosumers are more resilient and can handle more efficiently the energy transfer, citizens becoming empowered. The solution may apply in small and larger communities, being also a good starting point for designing the resilient Smart Cities of tomorrow.

4. Conclusions

The paper is introducing the *UniRCon* architecture, where prosumers owning local electricity generation such as PV can use an adequate storage control to transform their operation as to emulate an *always-a consumer* from the perspective of the DSO, with several advantages: on the utility side: reverse flow is avoided; the traditional load behaviour, for which the network has been designed, is kept; prosumers are empowered to control the local electricity inflow and energy balance, with prospects of achieving better grid stability due to reduction of effective grid-connected generators. Moreover, the operation in this load-only mode – labelled as *UniRCon* allows deployment of new optimization strategies. The paper compares three use-cases: classic net-metering, net metering with additional storage and resilient prosumer with load-only pattern, to be labelled as *UniRCon*. The analysis considers four timeline horizons, to be associated with technological and market expectations in 2018, 2020, 2022 and 2025. The assumed input data for each horizon is given in Table 1a and 1b (optimistic and traditional approach on investment costs) and the results for the three use-cases are given in figure 6a and 7b (summer and winter situations). One can observe that, for the studies cases, net metering with storage is superior in terms of prosumer savings (5.7% savings in classic net-metering with storage and additional 4.6% in UniRCon architecture), compared with classic net-metering; this is achieved since storage enables more auto-consumption when compared with feed-in based back injection, which encounters reductions payments towards unattractive levels, price parity being already reached in some countries. Moreover, by considering also in classic solutions a small tariff for DSO based increased resilience, the UniRCon solution increases the savings even more (8.6% compared with classic storage behind the meter), while offering full immunity and increased resilience to the prosumer.

The *UniRCon* solution allows the configuration of a DC bus on the prosumer premises, with advantages for integrating "naturally dc entities" like PV production and storage. This architecture is even more attractive than the storage-based net metering, as it gives additional savings (4.3% versus 6.7%) in the simulated scenarios, corresponding to optimistic and traditional approach in PV and storage investment calculation, respectively. This can be explained by the higher efficiency of conversion and local energy use, a less sophisticated connection of resilient loads and by the capacity of achieving local optimum for the energy use.

We conclude that *UniRCon* set-ups, ensuring a *load-only* pattern on distribution grid side, is superior to classic net-metering – with or without storage behind the meter, in both aspects: savings attractiveness and in resilience (the 2025 horizon is better in savings and also allows a 30 minutes resilience, making the *UniRCon* more tolerant to most of the grid outages). A levelized cost of electricity (LCOE) calculation may show lower benefits for all compared use-cases, thus not affecting the ranking, on which our study focused its work. This study can be a refinement of future work.

Future work will consider also equivalent costs on the grid side in order to increase resilience and/or to decrease the outages, which is expected an even more attractiveness of the UniRCon solution, as these grid related costs make higher the gap between the savings of the two solutions.

Finally, a preview of neighbourhood extension of the *UniRCon* architecture is also briefly presented in terms of principles and potential, having the same characteristics of individual prosumer transformed and projected at community / neighbourhood scale.

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