The value of prosumers' flexibility under different electricity market conditions: case studies of Denmark and Croatia

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Abstract –**To reduce greenhouse gas emissions, power system strategies have focused on large scale integration of renewable energy sources (RES) subsidizing initial installations for a fixed time period to ensure investment profitability. However, increasing number of wind and solar (PV) power plants, not responsible for scheduling deviations due to their intermittent production, resulted in growing need for power system flexibility. By rescinding incentives and subsidies and exposing RES to the market, they become responsible for accurate prediction of their production and become penalized for deviations from the announced forecasts.**

Moreover, the suppliers, or the aggregators, will play an important role in unlocking and encouraging the flexible end-consumers with installed local RES and demand response (DR). They need to create market products in a form of different dynamic pricing schemes which award responsiveness to price signals and penalize passive behavior.

The paper focuses on the value of household flexibility through electricity cost reduction in low and high developed energy power markets. Results show that households equipped with PV and different types of DR programs in high-liquid market (as one in Denmark), exposed to the volatile market prices and responsible for their PV production and demand forecast, achieve lower electricity cost comparing to poorly developed retail market in Croatia where consumers are better off in a two-price tariff system.

Keywords - **Demand response, dynamic pricing, market liquidity, renewable energy sources, two tariff pricing**

NOMENCLATURE

***Indices and Sets*:**

$d \in D$	Households
$s \in S$	Scenario
$t \in T$	Time

Parameters

$\underline{\boldsymbol{E}}$	Minimum state of charge of EV at the end of the day in kWh
$\overline{\boldsymbol{E}}$	Battery capacity of EV in kWh
$\boldsymbol{F_{1-4}}$	Coefficients of breakpoints used for piecewise linearization of battery maximum charging
$\boldsymbol{L^{ap}}$	Length of the cycle of uninterruptible appliances in hours (*ap*: washing machine, dryer, dish washer)
$\overline{\boldsymbol{P}}$	Maximum power of the EV charger in kW
$\boldsymbol{P^{uni\,ap}}$	Power of each uninterruptible appliances in kW (*ap*: washing machine, dryer, dish washer)
$\boldsymbol{R_{1-4}}$	Coefficients of breakpoints used for piecewise linearization of battery maximum charging
$\overline{\boldsymbol{SOC}}$	Battery capacity in kWh
$\boldsymbol{T_t^{max}}$	Upper bound for the room temperature in time *t* in ºC
$\boldsymbol{T_t^{min}}$	Lower bound for the room temperature in time *t* in ºC
$\boldsymbol{\pi_s}$	Probability of scenario *s*
$\boldsymbol{\lambda_t^{DA}}$	DA market price in €/kWh
$\boldsymbol{\lambda_t^{b}}$	Buying price set by supplier in ToU pricing in €/kWh
$\boldsymbol{\lambda_t^{s}}$	Selling price set by supplier in ToU pricing in €/kWh
$\boldsymbol{\eta}$	Energy efficiency
$\boldsymbol{\Delta t}$	Time interval (1 hour)

Stochastic parameters

$\boldsymbol{P_{d,s,t}^{ms}}$	Must-serve load *d* in scenario *s* and time *t* in kW
$\boldsymbol{PV_{d,s,t}}$	PV production *d* in scenario *s* and time *t* in kW
$\boldsymbol{T_{s,t}^{o}}$	Outside temperature in scenario *s* time *t* in ºC
$\boldsymbol{\lambda_{s,t}^{DOWN}}$	Down regulation price in scenario *s* and time *t* €/kWh
$\boldsymbol{\lambda_{s,t}^{UP}}$	Up regulation price in scenario *s* and time *t* €/kWh

Variables

$P_{d,t}^{b}$	Power imported from the grid in ToU pricing in kW
$P_{d,t}^{s}$	Power exported to the grid in ToU pricing in kW
$P_{d,s,t}^{GRID}$	Power imported (positive) /exported (negative) to/ from grid (household *d* scenario *s* time *t*) in kW
$P_{d,s,t}^{UP}$	Real time up regulation *d* in scenario *s* and time *t* in kW
$P_{d,s,t}^{DOWN}$	Real time down regulation *d* in scenario *s* and time *t* in kW
$P_{d,t}^{DA}$	Power contacted day ahead (household *d* time *t*) in kW
$P_{d,s,t}^{uni\,ap}$	Power of uninterruptable appliances *ap* in kW (household *d* scenario *s* time *t*)
$P_{d,s,t}^{def}$	Charging power of EV in kW (household *d* scenario *s* time *t*) -flexible deferable load
$P_{d,s,t}^{th}$	Thermal load (household *d* scenario *s* time *t*) in kW

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$P_{d,s,t}^{ch}$ Battery charging (household *d* scenario *s* time *t*) in kW

$P_{d,s,t}^{dis}$ Battery discharging (household *d* scenario *s* time *t*) in kW

$SOC_{d,s,t}$ Battery *d* state of charge in scenario *s* and time *t* in kWh

$T_{d,s,t}^{floor}$ Floor temperature in ºC (household *d* scenario *s* time *t*)

$T_{d,s,t}^{room}$ Room temperature in ºC (household *d* scenario *s* time *t*)

$T_{d,s,t}^{water}$ Water temperature in ºC (household *d* scenario *s* time *t*)

$\Delta SOC_{d,s,t}$ Maximum energy charging ability of the battery (household *d* scenario *s* time *t* in kWh

Binary variables

$b_{d,s,t}^{i}$ auxiliary binary variable determining the piecewise line segment on which $SOC_{d,s,t}$ lies

$x_{d,s,t}^{def}$ 1 if EV in household *d* is being charged in scenario *s* and time *t*

$x_{d,s,t}^{uni\ ap}$ 1 if uninterruptable flexible appliance *ap* in household *d* starts the cycle in scenario *s* and time *t*

I. INTRODUCTION

As the subsidy period of early installed renewable energy sources (RES) is coming to an end, development of new models and concepts to continue increasing the share of RES in future power systems is required. RES become balancing responsible parties and face penalties for their unscheduled production. Wind power plants cooperate with energy storages to increase the overall revenue by enabling more regulation capacities without harming battery's life [1]. Selecting the optimal capacity of battery storage can also lead to decreasing wind power curtailment, as well as reduce costs caused by curtailment [2]. Reduction of system operational costs and capacity increase of installed wind power plant ensuring system stability in [3] are carried out with cooperation of wind power plant with conventional generation and energy storage in hybrid power station on Greek isolated Samos Island. Coordination of a wind farm with a battery storage system based on modular multilevel converter in [4] with active and reactive power compensation results in smoothed power fluctuation, as well as in improved voltage at the bus of connected wind farm. The above concepts, and many others, show how coordinated operation of RES and flexibility units can reduce the uncertain and variable RES production and benefit the overall system costs and emissions.

When it comes to end-consumers with smaller installed capacity of renewable energy sources (such as rooftop solar panels PV), numerous approaches were considered to reduce consumer electricity cost either through integration of small-scale storage units or by deploying demand response (DR) programs. For example, in [5] optimal size of PV and household battery is defined with the goal of reducing annual electricity cost. The model compares results of time-of-use tariffs and real-time pricing, as well as stepwise power tariff, and includes subsidies of PV. The results show two things: i) in absence of peak-valley prices households do not need battery storage; ii) the integration and size of PV depends on subsidies. The authors of [6] show that DR programs under dynamic price mechanism with installed PV reduce the voltage deviation and smooth the load profile, as well as improve voltage stability. In [7] the authors defined several sizes of battery storages and PV with the goal of end-user cost minimization. However, they assume that excess of PV cannot be injected in the grid and battery storage discharging is used only for supplying household demand. The concept of sharing PV systems in energy community under different pricing mechanisms (feed-in-tariff, net metering, as well as net purchase and sell) is analyzed through game theory in [8]. The authors in [9] compare end-consumers electricity costs in several cases: i) without any distributed technology; ii) with installed PV; iii) with battery storage installation; and iv) with both technologies integrated with the end-user. End-consumers are exposed to spot market prices, but making profit from selling surplus of PV production is not considered. A similar cost-benefit study analysis is performed in [10] based on ToU rates in North Carolina, researching feasibility of investment in PV and battery storages. The result shows that if PV capacity exceeds the load, the investment is not profitable.

The above papers do not consider characteristics of individual consumer load nor PV forecast uncertainties. They usually relay on either existing ToU tariffs, while only a few simulate dynamic prices mechanism. Furthermore, PV installations are either considered to still be within the feed-in-tariff system or cannot sell the surplus of PV generation (installed only for self-consumption).

The paper is built on the existing work and presents benefits of exposing end-consumers with installed PV and different DR programs to volatile market prices. The responsibility for net load deviations is passed on consumers, meaning they are penalized in case they do not flexibly respond in periods of inaccurate forecasts. The role of the supplier is to pass on dynamic hourly prices to the end-consumers which reflect market prices as well as penalties for any deviations. By doing this, it is possible to clearly define the value of installing specific flexible units at the end-user premises.

The analyzes are carried out for two cases: i) for a well-developed, high-liquid market in Denmark, where the suppliers already create dynamic price signals and encourage their consumers to respond to system needs. In turn this results in lower electricity cost as compared to standard pricing; ii) in a developing, low-liquid market with low volatility of market prices and a single, dominant supplier. Here, most of the electricity is traded through bilateral contracts and dominant utility company owns majority of production units. In this case the results show that exposing end-consumers to real-time market prices, as compared to the existing two tariff system, is not profitable for them.

II. METHODOLOGY

In traditional pricing mechanism in Croatia, the end-consumer can choose between flat prices or two-tariff buying prices [11]. In case consumer has a rooftop PV panel installation, he does not have to forecast his production nor consumption, i.e. he is not responsible for supplier's deviation on the market and does not face any penalties. Most of PV installations are still remunerated for their production based on feed-in tariffs, however in case the PV system in not part of the scheme, the supplier in Croatia purchases the surplus of PV production from prosumer at 90% of average retail electricity price [12]. If end-consumers are not responsible for forecast deviations of the PV surplus injection in the grid due the intermittent nature of their rooftop PV production, broader integration of renewable sources on distribution level will require network reinforcement and additional flexibility in the system. On the other hand, the supplier can offer dynamic prices to end-consumer (same for buying and selling) which reflect the market prices and encourage consumers to predict their consumption and PV production by making them responsible for their deviation, as well as ensuring them lower electricity cost.

The goal of each consumer *d* is to minimize total cost for energy procurement, in traditional mechanism without prediction and penalties (1):

$$\min \sum_{s \in S} \boldsymbol{\pi_s} \sum_{t \in T} \boldsymbol{\Delta t} \cdot \left(\boldsymbol{\lambda_t^b} \cdot P_{d,t,s}^b - \boldsymbol{\lambda_t^s} \cdot P_{d,t,s}^s \right) \quad (1)$$

In market price scheme with real-time up and down regulation the cost minimization is (2):

$$\min \sum_{t \in T} \Delta \boldsymbol{t} \cdot \left[\begin{array}{c} \boldsymbol{\lambda_t^{DA}} \cdot P_{d,t}^{DA} + \\ \sum_{s \in S} \boldsymbol{\pi_s} \left(\boldsymbol{\lambda_{s,t}^{UP}} \cdot P_{d,s,t}^{UP} - \boldsymbol{\lambda_{s,t}^{DOWN}} \cdot P_{d,s,t}^{DOWN} \right) \end{array} \right] \quad (2)$$

Each consumer predicts the net load $P_{d,t}^{DA}$ for the upcoming day for hour *t* (positive $P_{d,t}^{DA}$ stands for buying, and negative for selling) at day-ahead stage (DA). According to the realization of scenario *s*, consumer needs to buy/sell more/less in real-time and faces penalties. Price for up-regulation $\boldsymbol{\lambda_{s,t}^{UP}}$ is always higher than the price at DA stage (if consumer needs to buy more at real-time stage, he will pay higher price comparing to the DA price for incorrect prediction). Price for down-regulation $\boldsymbol{\lambda_{s,t}^{DOWN}}$ is always lower than $\boldsymbol{\lambda_t^{DA}}$ (the excess of energy will be sold at lower price causing the profit loss). $P_{d,s,t}^{GRID}$ is a result of real-time net load of each consumer, and the deviation from forecasted net-load at DA stage is calculated as (3), making always just one variable (4) greater than zero in scenario *s* and time *t*:

$$P_{d,s,t}^{GRID} = P_{d,t}^{DA} + P_{d,s,t}^{UP} - P_{d,s,t}^{DOWN} \quad (3)$$

$$P_{d,s,t}^{UP}, P_{d,s,t}^{DOWN} \geq 0 \quad (4)$$

Import/ export $P_{d,s,t}^{GRID}$ from/to supplier is based on consumer's net load in scenario *s* and time *t* (5):

$$P_{d,s,t}^{GRID} + \boldsymbol{PV}_{d,s,t} = \boldsymbol{P_{d,s,t}^{ms}} + P_{d,s,t}^{uni\ wm} + \\ + P_{d,s,t}^{uni\ dw} + P_{d,s,t}^{uni\ dry} + P_{d,s,t}^{def} + P_{d,s,t}^{th} + P_{d,s,t}^{ch} - P_{d,s,t}^{dis} \quad (5)$$

Consumers under DR program supply must serve load $\boldsymbol{P_{d,s,t}^{ms}}$ and flexible load (either uninterruptable appliances $P_{d,s,t}^{uni\ dry}$, $P_{d,s,t}^{uni\ wm}$, $P_{d,s,t}^{uni\ dw}$, deferable charging of EV $P_{d,s,t}^{def}$, thermal flexible load $P_{d,s,t}^{th}$ or battery storage). The penetration of each flexible load will be studied in results.

Uninterruptable appliance (washing machine, dish washer and dryer) is started only once during the day (6):

$$\sum_{t=1}^{T-L^{ap}} x_{d,s,t}^{uni\ ap} = 1 \quad (6)$$

Eq. (7) ensures once cycle is started, it cannot be interrupted:

$$P_{d,s,t}^{uni\ ap} = \sum_{l=0}^{L^{ap}-1} x_{d,s,t-l}^{uni\ ap} \cdot \boldsymbol{P^{uni\ ap}} \quad (7)$$

For deferable load, such as electric vehicle (EV) charging, eq. (8) ensures that at the-end of charging period, the vehicle is fully charged or at the minimum level set by end-consumer:

$$\underline{\boldsymbol{E_d}} \leq \sum_{t \in T} \boldsymbol{\Delta t} \cdot P_{d,s,t}^{def} \leq \overline{\boldsymbol{E_d}} \quad (8)$$

EV can be charged only from late afternoon till morning, when the car is at home. It can be charged up to maximum power of the charger (9):

$$P_{d,s,t}^{def} \leq \overline{\boldsymbol{P_d}} \cdot x_{d,s,t}^{def} \quad t \leq 7, t \geq 18 \quad (9)$$

The battery storage system is modeled based on [13] where the charging power depends on battery's state of charge. Detail description can be found in [13].

$$SOC_{d,s,t-1} = \sum_{i=1}^{4} \boldsymbol{R_i} \cdot y_{d,s,t}^i \quad (10)$$

$$0 \leq y_{d,s,t}^i \leq 1 \quad (11)$$

$$\sum_{i=1}^{4} y_{d,s,t}^i = 1 \quad (12)$$

$$y_{d,s,t}^1 \leq b_{d,s,t}^1 \quad (13)$$

$$y_{d,s,t}^2 \leq b_{d,s,t}^1 + b_{d,s,t}^2 \quad (14)$$

$$y_{d,s,t}^3 \leq b_{d,s,t}^2 + b_{d,s,t}^3 \quad (15)$$

$$y_{d,s,t}^4 \leq b_{d,s,t}^3 \quad (16)$$

$$\sum_{i=1}^{3} b_{d,s,t}^i = 1 \quad (17)$$

$$\Delta SOC_{d,s,t} = \sum_{i=1}^{4} \boldsymbol{F_i} \cdot y_{d,s,t}^i \quad (18)$$

$$P_{d,s,t}^{ch} \leq \frac{\Delta SOC_{d,s,t}}{\boldsymbol{\eta} \cdot \Delta \boldsymbol{t}} \quad (19)$$

$$SOC_{d,s,t} = SOC_{d,s,t-1} + \boldsymbol{\eta} \cdot \Delta \boldsymbol{t} \cdot P_{d,s,t}^{ch} - P_{d,s,t}^{dis} \cdot \Delta \boldsymbol{t} \quad (20)$$

$$SOC_{d,s,t} \leq \overline{\mathrm{SOC}}_d \quad (21)$$

$$SOC_{d,s,0} = SOC_{d,s,24} = 0 \quad (22)$$

Correlations between flexible thermal load and room, floor and water temperature are presented with (23)-(25), while room temperature is bounded with minimum and maximum temperature based on consumer's comfort requirements (26)-(27) [14]:

$$T_{d,s,t}^{room} = \boldsymbol{a}_{11} \cdot T_{d,s,t-1}^{room} + \boldsymbol{a}_{12} \cdot T_{d,s,t-1}^{floor} + \boldsymbol{a}_{13} \cdot T_{d,s,t-1}^{water} + \boldsymbol{b}_1 \cdot P_{d,s,t-1}^{th} + \boldsymbol{c}_1 \cdot \boldsymbol{T}_{d,s,t-1}^{o} \quad (23)$$

$$T_{d,s,t}^{floor} = \boldsymbol{a}_{21} \cdot T_{d,s,t-1}^{room} + \boldsymbol{a}_{22} \cdot T_{d,s,t-1}^{floor} + \boldsymbol{a}_{23} \cdot T_{d,s,t-1}^{water} + \boldsymbol{b}_2 \cdot P_{d,s,t-1}^{th} + \boldsymbol{c}_2 \cdot \boldsymbol{T}_{s,t-1}^{o} \quad (24)$$

$$T_{d,s,t}^{water} = \boldsymbol{a}_{31} \cdot T_{d,s,t-1}^{room} + \boldsymbol{a}_{32} \cdot T_{d,s,t-1}^{floor} + \boldsymbol{a}_{33} \cdot T_{d,s,t-1}^{water} + \boldsymbol{b}_3 \cdot P_{d,s,t-1}^{th} + \boldsymbol{c}_3 \cdot \boldsymbol{T}_{s,t-1}^{o} \quad (25)$$

$$T_{d,s,t}^{room} \geq \boldsymbol{T}_{t}^{min} \quad (26)$$

$$T_{d,s,t}^{room} \leq \boldsymbol{T}_{t}^{max} \quad (27)$$

III. CASE STUDY

In traditional pricing mechanism prosumers are not obligatory to predict their net load. This role is passed on to the supplier who creates tariffs to ensure himself profit and to hedge against intermittent net load and market price volatility. With larger integration of renewable energy sources and increasing system need for flexibility, supplier creates incentives for consumers to reduce their bills through DR programs requiring their net load prediction. However, it is questionably in which cases and under which market circumstances this is feasible for both the supplier and end-consumer. The case studies demonstrate this on two countries, Croatia and Denmark, and define the value of both end-consumer flexibility units and developed retail market.

Traditional Time-of-Use prices in Croatia are shown in Table I (the reader should keep in mind that all listed prices in the paper are electricity costs only, without taxes, distribution and transmission network fee or supplier fee and other applicable costs). For Croatian prosumers ToU tariffs are currently the only available option. On the other hand, consumers in Denmark have the possibility of choosing between flat buying price or dynamic prices reflecting current market prices. As it can be seen from Fig.3., Orsted's (supply company in Denmark) buying dynamic prices [15] are higher than market prices. In addition, surplus PV production is sold at market DA price (unlike Croatia).

Bars in Fig. 1. present consumer's must serve load and lines present PV production in 5 scenarios, while Fig 2. shows outside temperature. DA Danish market prices, prices for up and down regulation in Fig. 3. are taken from Nord Pool [16]. Croatian DA prices are obtained from CROPEX [17] for 28th of October. Due to bilateral trading and lack of competitiveness in Croatia, up and down regulation are not part of the market. Up and down Croatian regulating prices are artificially simulated for the purpose of the model.

TABLE I TRADITIONAL PRICING MECHANISM IN CROATIA [12]

Low tariff (€/kW)	High tariff (€/kW)	Selling (€/kW)
0.0304	0.0620	0.0416

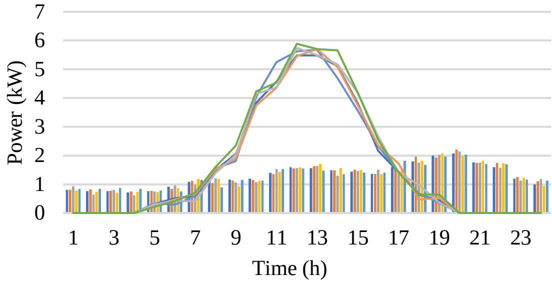

Fig.1. Must-serve load and PV production through scenarios

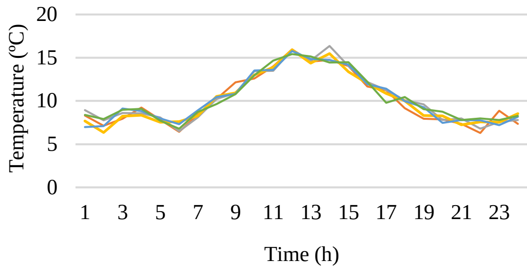

Fig. 2. Outside temperature

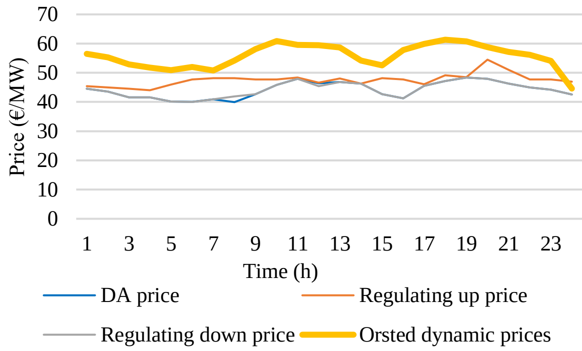

Fig. 3. DA and regulating prices at Nord Pool and Orsted dynamic prices

Consumers are equipped with a 3.7 kW EV charger. It is assumed that the EV battery (30 kWh capacity) is empty before connecting to the charger. At the end of flexible charging, according to consumer's preferences, battery's SOC is set between 25.9 kWh and 30 kWh (8). In cases 1 and 2 mentioned below, EV is being charged at maximum power 3.7 kW for 7 hours resulting in battery's SOC 25.9 kWh. To ensure the same energy consumption for flexible EV charging, the same amount is set as minimum SOC in cases 3 and 4.

Power and cycle length of uninterruptable appliances are shown in TABLE II, while consumer's comfort temperature bound in Fig. 4. Coefficients for temperature regulation are obtained from [14].

TABLE II UNINTERRUPTABLE LOAD CHARACTERISTICS [18]

Appliance ap	Power $P^{uni\ ap}$ (kW)	The length of the cycle L^{ap} (h)
Washing machine (wm)	2	3
Dryer (dry)	2.5	2
Dish washer (dw)	1.9	1

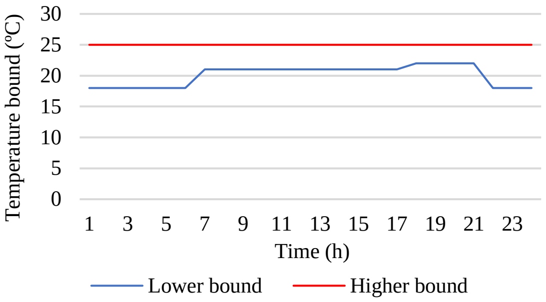

Fig. 4. Temperature bound set by end-consumer

IV. RESULTS

TABLE III compares end-consumer's cost in Croatia and Denmark with traditional pricing and market pricing. Four different DR cases are analyzed:

1) The consumer has PV and the only flexible load is the thermal one. This also means that the must-serve load (Fig. 1.), as well as the rest of the load has predefined behavior: the consumer turns the washing machine on at the begging of hour 22, dryer at hour 23 and dish washer at hour 24, and charges his vehicle from hour 23 to hour 5 at the same maximum power 3.7 kW (at the end of charging period car's battery SOC is 25.9 kWh);
2) Same as the case 1, but the consumer in addition has also a battery storage unit of 1 kW and 1 kWh;
3) The consumer has PV, flexible thermal load and flexible EV charging (deferable load), while the supply of uninterruptible appliances and must-serve load is the same as in the case 1;
4) The consumer has PV, supplies must-serve load, flexible thermal load, flexible uninterruptible load (starting hour of washing machine, dish washer and dryer is not fixed) and flexible EV charging (flexible deferable load).

TABLE III COST IN CROATIA AND DENMARK UNDER DIFFERENT PRICING MECHANISM

Country	Pricing	Case 1 (€)	Case 2 (€)	Case 3 (€)	Case 4 (€)
Croatia	ToU	1.1219	1.0962	1.1219	1.1219
	Market	1.8062	1.8038	1.6949	1.5890
Denmark	Dynamic	2.0398	1.9091	1.5562	1.1899
	Market	1.5812	1.58119	1.5128	1.4585

A. *Value of flexibility in traditional pricing*

As it can be seen from TABLE III in traditional ToU pricing mechanism in Croatia, having flexible EV charging in case 3 and in addition uninterruptable flexible appliances in case 4 does not reduce end-consumer's cost. Because of the flat low price during the night, there are no savings when altering the time in which EV is charged (as well as charging power) or shifting the operation hours of uninterruptable load.

Case 2 in Croatia shows 2.29 % of savings with integration of battery storage. Fig. 5. shows battery storage charging during the low tariff period in the first 4 hours with energy bought from the supplier or during the morning from PV excess (hours 9-10) and then discharging during the high tariff when there is insufficient PV production.

B. *Value of flexibility in dynamic market pricing*

In both countries there is an extra cost saving when adding a new type of DR program to end-consumer's portfolio under dynamic pricing scheme. As it can be seen from TABLE III, the consumer in Croatia in case 4 saves 12 % comparing to case 1. Consumer in Denmark can reduce the electricity bill for almost 8 % when adding new programs of DR. As it can be seen when comparing results in Fig. 6. and 7., for case 4 in Denmark with more flexible options participate in DR program under market prices, net load drastically changed during the valley prices at the begging of the day. All uninterruptable appliances are switched on during those hours, ensuring big cost reduction comparing to the case 1 when consumers turn them on before going to bed.

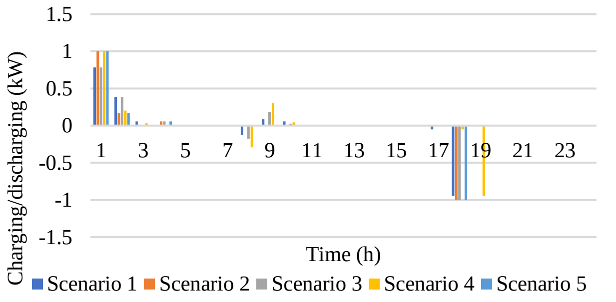

Fig.5 Battery charging and discharging in Croatian ToU pricing

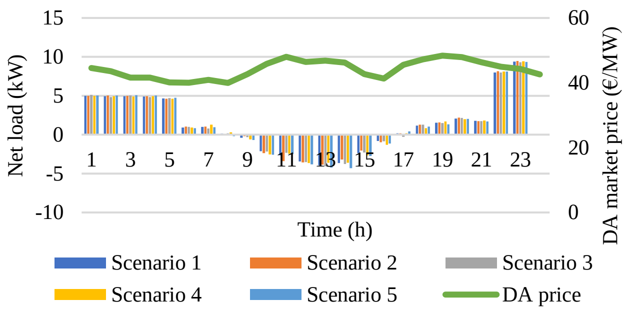

Fig. 6. Net load in case 1

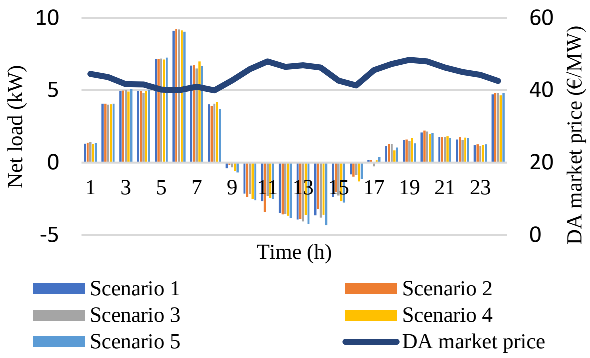

Fig. 7 Net load in case 4

C. The impact of market liquidity on end-consumers

In high-liquid markets with many bids and offers, as one analyzed here in Denmark, competitiveness determines the market price ensuring consumers lower electricity cost when exposed directly to the market prices. On the other hand, the majority of energy in Croatia is traded through bilateral contracts resulting in low-liquid market with very high market prices (even higher than supplier's prices on instances). The end-consumer's cost increases significantly if consumer is exposed to CROPEX market prices. Furthermore, there is no balancing market in Croatia and Transmission System Operator is responsible for ensuring security of power system by procuring balancing services through bilateral contracts with the only utility company capable of providing auxiliary services.

V. CONCLUSION

To encourage broader integration of RES in the line with low-carbon policies, supplier (or aggregator) offers dynamic prices to end-consumers reflecting market prices. To enable dynamic prices, supplier must protect itself against consumers' volatile behavior and hedges this risk by making them responsible for deviation from predefined DA schedule.

The results show the benefits of different flexibility options under dynamic prices comparing to the traditional pricing. A significant cost reduction occurs with higher penetration of flexible appliances comparing to ToU pricing where the flat prices do not fully exploit the flexibility of DR.

Developing and developed markets exhibit different market prices at power exchanges. The results indicate the need for forming complete power market in Croatia to encourage competition and reduce market prices. Additionally, competition on retail level results in lower prices for end-consumers, penalizing the passive ones and creating opportunities for investing in flexible units and responding to system needs.

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