PV Self-Consumption and Tariff Design Impact on Retail Energy Markets

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Abstract

The rapid decline on PV technology costs, the attractive efficiency increase on PV panels available for the residential sector and European Parliament public policies on energy in order to address the climate change issue have substantially increased the number of consumers that have decided to start producing energy, coining a new term: the PV prosumer.

The main goals of the present work are to identify the main challenges posed by prosumers to the system and the current issues that are arising in energy markets due to PV prosumers integration. Additionally, one methodology have been developed to quantify cross-subsidization among customers and another already existing method has been adapted to this work's data and requirements for the system loss of welfare analysis. In both methodologies, different markets and retail tariff designs have been considered being able to assess the impact of these different tariff structures in energy markets.

Results obtained showed that cross-subsidization exists among ratepayers, being more subsidized prosumers with higher PV installed capacities and under the Dual Rate Tariff Structure in the Free Market. In that sense, when the retail tariff fixed component is increased, cross-subsidization tends to diminish. It has also been observed that in all cases there is a loss of welfare in the system when a prosumer is integrated, whatever its PV installed capacity is. Additionally, this work tariff proposal is able to mitigate cross-subsidization and significantly reduces system loss of welfare.

Keywords:

Energy Economics, Energy Markets, PV Prosumers, Cross-Subsidies, Loss of Welfare.

1. Introduction

Prosumers are consumers that generate their own electricity and, consequently, they reduce their energy consumption from the grid. However, most of them still need the grid and, in peak hours, they withdraw energy from the system, so they still have the option to get that electricity. This is the reason why PV panels are seen somehow as an energy efficiency measure. On the other hand, part of the fixed costs are included in the tariff variable or volumetric part. Hence, if consumption is reduced, fixed costs are not recovered and other customers must assume extra costs. This phenomenon is a particular kind of cross-subsidization that will be explained further on. This work will pay special attention to the particular phenomenon of cost allocation distortion due to the energy efficiency effect of PV panels owned by prosumers.

In that sense, the tariff design and structure will play an important role on the mitigation of this effect. The main issue of fixed costs recovery underlies on a non-realistic tariff design that does not allocate costs properly. Challenges could arise when determining the non-volumetric weight on the overall tariff, but also on the charge structure for the volumetric part.

Additionally, the PV prosumers impact on energy markets is another must in this study purpose. Together with DG distortion to energy markets in a more general perspective, PV subsidization impact on investment identification signs and on the energy market equilibrium has to be properly studied.

Regarding cross-subsidies, as it will be the dominant and primary interest of this study, it must be said that no general accepted definition or quantification method has been established. It is not easy to define cross-subsidies because they are difficult to measure, and they are challenging to measure because it is hard to define them (1). Therefore, a specific approach for a particular type of cross-subsidies will be analysed.

2. Prosumer's Impact on Energy Markets

Foremost, it must be mentioned that the operational challenges that prosumers pose on the energy system are also important. PV prosumers are a particular kind of Distributed Generation based on RES that produce non-dispatchable energy by means of PV panels. Prosumers produce energy under a stochastic regime and in periods when the prosumer has an excess of energy, which can cause some issues on the network. First, the mismatch of PV production peak with the consumption peak, which will make the overall costs of the network remain the same and may cause some congestions in the network. Second, in case that the prosumer has an energy excess and the destination load is not close, network losses could increase. Third, other technical aspects like network protection and voltage profiles can be affected by the integration of PV energy in the grid.

Additionally, PV prosumers integration are arising issues on current energy markets. Firstly, RES integration in the market reduces the wholesale electricity price, as its marginal cost in the spot market auction is zero. The average price of all European Energy Markets has decreased from 50€/MWh to 40€/MWh between 2012 and 2015 (2). Secondly, and consequently, there is a mismatch between the wholesale and the retail price due to the RES deployment and the no-decrease of investment costs in conventional technologies. Thirdly, low or even negative prices in European Energy Markets are not showing efficient signs for investment and operational behaviour, discouraging investment in new capacity. Ultimately, the fact that prosumers are reducing consumption together with the current variabilization of fixed costs in the retail tariff volumetric part arises cross-subsidies among customers, making them more vulnerable to an increase in retail tariffs, phenomenon known as consumer divide. Moreover, cross-subsidization and a higher capital cost for PV compared to other technologies can also produce a system loss of welfare, affecting the overall consumer, prosumers and regular ratepayers.

In that sense, this study has developed a methodology to quantify cross-subsidization caused by the prosumers' reduction on consumption and has adapted another already existing methodology to quantify the system loss of welfare.

3. Methodologies

<u>Cross-subsidies in the energy sector</u>

Cross-subsidies will appear when avoiding fixed costs payments included in the tariff variable component, which has been reduced due to the PV self-consumption. First, reduction on consumption must be identified. In that sense, two situations are considered: if demand (D) is larger than PV production (P) *[1]* or if it is smaller *[2]*.

$$if\ D - P \geq 0 \rightarrow \boldsymbol{P} \quad [1]$$

$$if\ D - P < 0 \rightarrow \boldsymbol{D} \quad [2]$$

In *[2]*, excess PV energy injected in the grid is not considered, as it will be very difficult to isolate cross-subsidies only arising from the fixed costs payment avoidance. Therefore, costs associated to the distribution network, access tariffs, etc. related to the energy injected will be disregarded, as well as the compensation for the energy injected into the grid. For the first case, if demand is larger than production, cross-subsidization will be given by *[3]*. PV production will depend on the year global irradiation. One profile will be obtained from February and will be used for all the winter period, from October to March, and the same will occur with the July profile for the summer period.

$$Cross - Subsidies = PV\ production\ (kWh) \cdot Tariff\left(\frac{€}{kWh}\right) \cdot \%Fixed\ Costs\ Variablized \quad [3]$$

For the second case, when demand is less than PV production, only the energy demand must be considered. Cross-subsidies in this scenario are given by *[4]*.

$$Cross - Subsidies = EnergyDemand\ (kWh) \cdot Tariff\left(\frac{€}{kWh}\right) \cdot \%Fixed\ Costs\ Variabilized \quad [4]$$

In this methodology, four variables must be defined: demand, PV production, tariff volumetric part and the percentage of fixed costs variabilized in the volumetric part. Data discretized in 15 minutes periods is required to analyse dynamics occurring either when PV production is higher than demand and vice-versa.

Demand profiles

Demand profiles were generated using a new method to create low-voltage synthetic load profiles designed by J. A.C Machado, P. M. S. Carvalho and L. A. F. M Ferreira in (3).

PV Production

First, radiation values have been obtained in the Institute for Energy of the Joint Research Centre for the European Commission (4). The inclination angle considered for the panel is 35º facing south, and the radiation is calculated in this conditions (G_{eff}). Solar Daily Radiation for all days in winter (from October to March, using data from February) remains constant and the same happens for the summer period (from April to September, using data from July). Hence, only two radiation profiles are considered.

The efficiency (η) of the panel is assumed 15% and its degradation is considered 0% annually. The performance ratio of the installation is calculated (PR) assuming that the average solar access is 95%, the inverter efficiency is 96%, the module temperature derate factor is 0.88 and the ratio of converting from DC to AC is 0.94 (5), and it is given by *[5]*.

$$PR = 0.95 \cdot 0.96 \cdot 0.88 \cdot 0.94 = 0.75 \quad [5]$$

Then, system's PV output will be given by *[6]*:

$$PV_{output}(kW) = G_{eff}\left(\frac{kW}{m^2}\right) \cdot A_{PV\ system}(m^2) \cdot \eta \cdot PR \quad [6]$$

The PV system area will be determined by the installed PV capacity. Total installed capacity of the installation must be sized taking into account the customer profile demand and will vary according to the customer needs. The criterion to determine the installed capacity will be that the installed capacity should be equal to the average demand power of the customer taking into account the installation performance ratio, as expressed in *[7]*. Values found will be rounded off to the lower value in the following scale: 300W, 600W, 900W, 1200W and 1500W. Those are the considered available PV arrays that the prosumer can install according to its demand. PV modules of 300W and 2m^2 of area are the single units to assemble bigger PV arrays.

Demand for daylight hours has been considered, from 5h to 19h as an approximation for the annual average matching the PV production interval in summer given by (4). Additionally, average sunshine hours in winter (from October to March) have been calculated according to EU data in (6). Data is presented in *Table 1*.

Once all the data is gathered, the PV system area can be obtained by means of *[7]*.

$$A_{PV\ System}(m^2) = P_{installed}(kW) \cdot A_{specific}\left(\frac{m^2}{kW}\right) = \frac{Winter\ Demand\ (kWh)\ within\ PV\ production\ interval}{Nº sun\ hours\ for\ winter \cdot PR} \cdot \frac{A_{1panel}(m^2)}{0.3\ kW_{1panel}} \quad [7]$$

Given the fact that the PV output will be calculated in periods of 15 minutes, in order to obtain the energy value, it will be multiplied by 0.25h, as shown in *[8]*.

$$PV_{output}(kWh) = PV_{output}(kW) \cdot 15(min) \cdot \frac{1h}{60min} = PV_{output}(kW) \cdot 0.25h \quad [8]$$

Month	Days	Sunshine (h)	Monthly Av. (h)	Winter Av. (h)
October	31	208	6,71	5,50
November	30	157	5,23	
December	31	142	4,58	
January	31	142	4,58	
February	28	150	5,36	
March	31	203	6,55	

Table 1. Sunshine hours for winter in Lisbon (6).

Tariffs

Tariffs structures applied are based in the ERSE's 2016 tariffs and prices for electricity. Three different tariffs options are considered for a 6.9 kVA demand profile for regular low voltage clients in the regulated market: simple, bi-hourly (dual rate) and tri-hourly (triple rate). The tariff structure has also been discretized in 15 minutes periods to proceed with calculations. In that sense, only the volumetric charges have been considered, as they are the only affected by a decrease on consumption.

Fixed Costs Variabilization Percentage

Total system costs structure consists in 75% fixed and 25% variable. With regard to the revenue structure for low voltage normal clients in the regulated market, or BTN ("Baixa Tensão Normal"), the 80% correspond to the variable component and the 20% to the fixed part. Considering that the fixed component in the retail tariff is fully allocated to recover fixed costs, 58% of total costs that are fixed will need to be charged in the tariff variable part. Therefore, considering that revenues coming from variable charges represent the 80%, fixed costs will account for 71% of the volumetric part in the retail tariff.

System Loss of Welfare

Firstly, if the present value (Pv) of buying, installing and operating a distributed PV system is less than the present value of purchasing the same amount of electricity from the grid, then the PV panel owner has a benefit on adopting the solar PV system. Additionally, if the present value of the purchases avoided by the prosumer from the grid is less than the present value of the cost of substituting the system's energy generated by the solar energy, the non-PV owners will be benefitted. From the overall ratepayer point of view, if the present value of buying, installing and operating a PV system is less than the present value of generating and distributing the same electricity produced by other technologies, then the system becomes more cost-effective. To quantify the wealth transfers among customers (or stakeholders), the Net Present Value (NPV) balance is considered and it is explained in the following section. NPV for panel owners, non-PV owners and overall ratepayers are given by *[9]*, *[10]* and *[11]*.

$$NPV_{owner} = PV_{price\ grid} - PV_{cost\ solar} \quad [9]$$

$$NPV_{non-PV\ owners} = PV_{cost\ grid} - PV_{price\ grid} \quad [10]$$

$$NPV_{overall} = PV_{cost\ grid} - PV_{cost\ solar} \quad [11]$$

On the other hand, the NPV for the overall ratepayers can also be calculated as in *[12]*.

$$NPV_{overall} = NPV_{owner} - NPV_{non-PV\ owners} \quad [12]$$

In order to determine the NPVs for the different stakeholders, the present value (Pv) for the cost of installing and operating a distributed solar PV array, for the avoided grid electricity purchases and for the cost of grid electricity that solar PV displaces are calculated by means of *[13]*, *[14]* and *[18]* respectively.

First, the present value for the cost of buying, installing and operating a PV panel will be obtained from computing the value evolution over time of the solar panel cost and taxes, the loan acquired and the discount rate on the investment.

$$PV_{(Cost\ Solar)} = \sum_{n=1}^{N} \left(c \cdot (1+r)\right) \cdot \left(\frac{i_L \cdot (1+i_L)^N}{(1+i_L)^N - 1}\right) \cdot \left(\frac{1}{(1+d)^n}\right) \qquad [13]$$

where c stands for the array costs in €, r for the value added tax rate, i_L for the nominal loan interest rate (real loan interest + inflation), d stands for the nominal discount rate (real discount rate + inflation), h for a 15 minutes period and n for the annual index.

Second, the present value for avoiding electricity purchases from the grid will consider two situations in each period of analysis, depending if energy demand is higher than PV output. In this case, if PV generation is smaller than demand, the prosumer's benefit will be equal to the volumetric part of the tariff multiplied by the energy generated, which is the monetary savings in purchasing electricity from the grid, as shown in *[15]*. On the other hand, if PV generation is greater than demand, and can be injected in the grid, the benefit for the prosumer will be the energy not purchased from the grid plus the energy injected, as given in *[16]*. Portugal rewards PV prosumers with the 90% of the spot market (MIBEL) price at that time. If energy injected in the grid is not remunerated, then the last equation must be used, which represents the same situation that in the first case when demand was greater than PV generation *[17]*.

$$PV_{(Price\ Grid)} = \sum_{n=1}^{N} \left(\sum_{h=1}^{24} b_{h,n}\right) \cdot 365 \cdot \left(\frac{1}{(1+d)^n}\right) \qquad [14]$$

The value of $b_{h,n}$ will depend on the following condition:

Condition	*Value*	
$g_h \leq q_{h,i}$	$b_{h,n} = g_h \cdot T_h \cdot (1+inflation)^n$	*[15]*
$g_h > q_{h,i}$	$b_{h,n} = \left(q_{h,i} \cdot T_h + \left(g_h - q_{h,i}\right) \cdot 0.9 \cdot LMP_h\right) \cdot (1+inflation)^n$	*[16]*
	$b_{h,n} = g_h \cdot T_h \cdot (1+inflation)^n$	*[17]*

Table 2. Compensation of PV energy according to system loss of welfare methodology.

where $b_{h,n}$ is the monetary benefit of each unit of solar PV generation, g_h is the solar PV generation, $q_{h,i}$ is the panel owner electricity demand without considering self-consumed solar PV, T_h is the retail tariff applied at a residential level for BTN clients of 6.9kVA, LMP_h is the MIBEL Portuguese wholesale daily average price for 2015 in 15 minutes discrete periods, $inflation$ is the annual rate growth for retail tariffs and MIBEL price due to inflation, d stands for the nominal discount rate (real discount rate + inflation), h for a 15 minutes period and n for the annual index.

Third, present value for the system or grid electricity that solar PV substitutes will take into account the distribution and transportation losses to deliver electricity and the average generation cost of the other technologies being displaced, as it is shown in [18].

$$PV_{cost\ grid} = \sum_{n=1}^{N} \left(\sum_{h=1}^{24} g_h \cdot C_{gen,h} \cdot (1+l_{trans}) \cdot (1+l_{dist})\right) \cdot \left(\frac{1}{(1+d)^n}\right) \qquad [18]$$

where g_h is the PV generation in 15 minutes intervals, $C_{gen,h}$ is electricity generation cost for the grid minus the benefits obtained by emitting less CO_2, l_{trans} stands for the transportation loss rate, l_{dist} is the average distribution losses rate, d stands for the nominal discount rate (real discount rate + inflation), h for a 15 minutes period and n for the annual index.

In this methodology, many variables are considered. Explanation of data and assumptions are given for each present value calculated. With regard to the demand profiles, tariffs and PV production output, the same procedure as in the methodology to determine cross-subsidies has been applied.

Present value for the cost of buying, installing and operating a PV panel

PV panel cost has been determined through the specific price per watt for different capacities. It is difficult to determine a common established price for commercial PV. However, this study considers the judgments in (7), to determine price in € per watt. A logarithmic equation has been created to approximate the values in (7) by adapting them to the PV capacities considered in this work, which is given by *[19]*.

$$€/W = -0.734 \cdot \ln(PV\ capacity) + 6.85 \qquad [19]$$

Representative prices for different PV panel sizes, as well as the total costs after taxes, are presented in *Table 3*. The array cost could be subjected to modification in a range from -25% to 25%, which will allow to develop a sensibility analysis. Base case is presented in Table 3.

P(W)	**300**	**600**	**900**	**1200**	**1500**
Price (€/W)	2.7	2,2	1,9	1,6	1,5
c (€)	810	1320	1710	1920	2250
r	23%	23%	23%	23%	23%
Total Cost (€)	996,3	1623,6	2103,3	2361,6	2767,5

Table 3. Prices for purchasing and installing a PV panel.

Several cases are considered depending on the PV panel life expectancy (N): 10, 15, 20 and 25 years. Different results collected for each case will serve as a sensibility analysis. Additionally, a real discount rate of 5% has been taken into account, which makes a nominal discount rate for the investment of 7% by means of *[20]*. Real discount rate can also be modified and take the following values: 1%, 3% and 5%. Regarding the interest loan for purchasing the PV panel, it has been fixed at a real value of 5%, which turns out in a nominal value of 7%. Ultimately, no sensibility analysis has been carried out for the loan interest rate as suggested in (7), due to its low impact in the present value.

$$Rate_{nominal} = (1 + Rate_{real}) \cdot (1 + inflation) - 1 \qquad [20]$$

Present value for avoiding electricity purchases from the grid

For calculating the present value of avoided purchases from the grid, the main variables that are called upon to play an important role are demand profile, PV generation, tariff structure and the spot market price (MIBEL). As the first three variables have been already discussed, only spot market price will be explained. Demand profiles and PV production output are discretized in periods of 15 minutes for an annually or seasonally average day. MIBEL daily average price for each period of 15 minutes from 0h to 23:59h has been calculated in order to match prosumer's demand and solar production data structure. Data from MIBEL has been obtained from EDP and it belongs to 2015. In case of market splitting, prices are referred to the Portuguese wholesale market. Ultimately, an inflation rate of 2% annually has been considered as the electricity price growth rate and the same annual increase has been considered for the MIBEL price.

Present value for the system or grid electricity that solar PV substitutes

Generation costs for other technologies electricity generation has been set up at 50€/MWh at the base case, although it can be modified from 20 to 80€/MWh to conclude the potential impact on the base case results. The benefits of substituting energy from the grid by solar would be the price of CO_2 in the EUA (European Allowances for emissions) multiplies by the average factor emission of Portugal. Additionally, it has been assumed that PV generation avoids an average of 10% as distribution system loss rate and 1.5%

as transmission losses. Ultimately, it has been assumed that the generation cost grows with inflation (considered as 2% annually).

The involvement of many factor in this methodology requires a sensitivity analysis to assess the impact of changes in their values. Therefore, settling a sensitivity analysis structured in a Low Overall NPV, Base Case and High Overall NPV, is mandatory.

	Low case	Base case	High case
N (years)	15	20	25
Mibel price (€/MWh)	-25%	0%	25%
PV price (€/W)	25%	0%	-25%
Discount rate (%)	3%	5%	7%
Grid generation cost (€/MWh)	20	50	80
Tariff seasonality	Winter	Summer	Summer
Weather conditions	Winter	Summer	Summer

Table 4. Sensibility Analysis Scenarios.

4. Results

<u>Cross-subsidies in the energy sector</u>

Current Cross-Subsidization in the Regulated Market

Cross-subsidies rise with PV installed capacity as more energy is self-consumed and less energy is consumed from the grid. According to the results, a prosumer with 1500W of installed PV and being charged through a Dual Rate tariff is avoiding annually around 204€, while a prosumer with only 300W of installed capacity and Simple tariff design is evading 44€ in terms of fixed costs. It has been observed in that for all the PV arrays, the Dual Rate (Bi) tariff is always cross-subsidizing prosumers more than the Simple and Triple Rate designs. If the tariffs designs are analysed into more detail, it is found that, within the PV production period, electricity retail prices are higher, which makes more valuable the energy self-consumed by prosumers.

Regulated Market vs Free Market

When comparing the results obtained for the Free and Regulated Market, it can be said that there is not a big difference, although the tendency shows that higher wealth transfers occur in the Free Market from regular ratepayers to prosumers. The fact that in the Free Market cross-subsidies are higher it can be explained because of the higher retail price in the PV production period, valuing more the self-consumed energy. Additionally, as the retail price for the Simple Tariff design is the same in both markets, no difference in cross-subsidization will be found between prosumers in that case.

Tariff Assessment

In *Table 5*, cross-subsidies for different revenues structures and different PV arrays are shown.

	Annual Cross-Subsidies (€)			
Fixed Component Share	18,9%	30,0%	50,0%	70,0%
300W	47	44	35	14
600W	76	71	57	23
900W	104	97	78	32
1200W	135	126	101	42
1500W	193	181	144	60
Average Difference	-	-6%	-25%	-69%

Table 5. Annual Cross-Subsidies for different fixed revenues component.

As it can be observed, cross-subsidies are substantially reduced when increasing the fixed component in the retail tariff.

Additionally, different designs for the volumetric retail tariff component will also have an impact on the avoidance of fixed costs by prosumers. If the energy consumed within the PV production period is more valuable than without, then, cross-subsidization will be higher. In that sense, increasing flexibility in the demand side will help to mitigate the problem if alternative tariffs reflecting that phenomenon are applied.

A feasible solution would be to reduce the value of electricity within the PV production period and increase the value for the rest of the day. In this work, an alternative tariff design has been created according to the following constrains: not affecting the total revenue (making it invariable), not changing more than 30% the price in each period and reducing cross-subsidies by at least 5%. The proposal is presented in Table 6 and it is compared to the current structure for the Regulated Market BTN clients for 6.9kVA.

	Period	Current (€/kWh)	Proposal (€/kWh)	Difference
Simple	-	0,1634	0,1634	0%
Dual	Out of Valley	0,1909	0,1700	-11%
	Valley	0,1002	0,1300	30%
Triple	Peak	0,2169	0,2300	6%
	Out of Valley	0,1716	0,1420	-17%
	Valley	0,1002	0,1200	20%

Table 6. Alternative Volumetric Retail tariff design.

The results obtained for that tariff designed are presented in Table 7.

W	RM (€/year)	FM (€/year)	Proposal (€/year)
300	47	48	44
600	76	78	71
900	104	107	97
1200	135	138	126
1500	193	198	180
Average	111	114	104
Difference	-7%	-10%	-

Table 7. Comparison of annual cross-subsidies for the Free Market, the Regulated Market and the Tariff Proposal.

<u>System Loss of Welfare</u>

Base Case

In all the cases, for all the PV installed capacities and under the same retail tariff structure, there is a system loss of welfare quantified by the NPV for the overall ratepayer, going from the 600€ in the 600W case to 225€ in the 1500W scenario. One of the main reasons for that is that capital costs for PV have an important impact in the system loss of welfare and do not follow a lineal tendency. *Table 8* shows that for higher PV installed capacities, the system loss of welfare is diminished, except from 300W to 600W and from 300W to 900W, which as seen in Equation *[11]*, depends on the present value for the system electricity that PV substitutes and on the present value for the cost of a solar PV array. However, it can be stated that the tariff design will not have an impact on the system loss of welfare, but on the cost or benefit allocation between PV panel owners and non-PV panel owners.

With regard to PV panel owners, the benefit of installing a PV panel array will depend on the capacity installed and on the volumetric retail tariff. For higher capacities, PV panel owners will obtain larger benefits.

Regarding non-PV owners, in all cases, for each prosumer that installs a PV array at his or her home, the other ratepayer will be negatively affected assuming the costs caused by it, which can be explained by a higher LCOE for solar PV than other generation technologies. A regular ratepayer will be paying in 20 years an additional cost valued from 575€ every time a PV array of 300W is integrated to 2304€ when a 1500W PV module is installed, both subjected to the simple tariff.

Ultimately, from the overall perspective, it must be highlighted that the loss of welfare is higher for PV arrays of 600W and 900W than for 300W. One possible explanation would be that the cost of going from 300W to 600W and 900W of PV installed capacity is still greater than the benefit the prosumer will gain.

W	Tariff	NPV owner (€)	NPV others (€)	NPV overall (€)
300	Simple	87	-575	-488
300	Dual Rate	179	-667	-488
300	Triple Rate	124	-612	-488
600	Simple	309	-915	-607
600	Dual Rate	458	-1064	-607
600	Triple Rate	371	-978	-607
900	Simple	659	-1237	-578
900	Dual Rate	874	-1452	-578
900	Triple Rate	746	-1324	-578
1200	Simple	1244	-1572	-328
1200	Dual Rate	1525	-1852	-328
1200	Triple Rate	1361	-1688	-328
1500	Simple	2079	-2304	-225
1500	Dual Rate	2499	-2724	-225
1500	Triple Rate	2275	-2500	-225

Table 8. System Loss of Welfare Results for the Base Case in the regulated Market.

Sensibility Analysis

It can be concluded that the factor that most affects the net present value for prosumers is the season of the year, as the PV output and the retail tariff structure depend on that. The PV panel price and its lifetime also influence a lot the NPV for PV owners. A decrease in the PV panel price, as expected for the next years, will definitely be a driver for more consumers to become prosumers, as the benefits of installing a PV array are obvious. On the other hand, the grid generation costs will not have any impact on the NPV for owners when installing a PV array. MIBEL price and the investment discount rate are considered to have a moderate impact on the prosumers NPV.

Furthermore, it has been observed the NPV for the other ratepayers is mainly driven by the system generation costs. If the generation costs for regular technologies are increased then solar PV becomes competitive and can bring down the costs of the system. Therefore, if generation costs rise, NPV for other ratepayers increases as the system is consuming cheaper energy served by solar PV. On the other hand, if the system generation costs decrease then the energy served by solar PV is more expensive and the system becomes less cost-effective decreasing the NPV for the non-PV owners.

In the NPV overall case there are mainly two variables dominating the NPV value: system generation costs and the PV array price. In the first case, if generation costs rise, the system will gain fare because the system electricity is being substituted by a cheaper energy source. On the other hand, if prices decrease, then solar is more expensive and is making the system less cost-effective, as mentioned in the previous paragraph. With regard to the PV array price, if it decreases, the system loss of welfare will be almost zero as it is consuming electricity at a lower investment price, and if they increase, the opposite situation will occur. It is important to highlight that an increase in 30€ in the generation costs can make the system gain welfare, as well as for the PV price, which can make the system gain welfare only by decreasing a bit more than 25%. The season considered, meaning the PV output and the tariff structure can also have an impact by decreasing the NPV in winter conditions. Ultimately, the PV panel life expectancy also impacts moderately the system welfare.

Tariff Assessment

For all markets, even this work's tariff proposal, the Dual Rate structures offer more benefits to prosumers, which means that all the structures are still valuing more the energy consumed in the PV production period. In that sense, the most benefitted prosumer is in the free market with a Dual Rate structure. On the other hand, the less benefitted prosumer is under this work's proposal tariff conditions with a Triple Rate structure. Additionally, it can be observed that generally free market benefits more prosumers, while the alternative proposal reduce prosumer's incentives.

On the other hand, other ratepayers are being more disadvantaged by the free market, the regulated market and the alternative proposal in this order. The regular ratepayers in a Dual Rate tariff structure are also being more badly affected than the other time structures, so a regular ratepayer in the Free Market and with a Dual Rate tariff will be assuming around 1530€ in 20 years for a 900W prosumer, while with the alternative proposal it would be 1260€.

Ultimately, for the overall system welfare there is no difference between markets or tariff time structures. From that, it can be concluded that the tariff structure is only affecting how much the prosumer are being benefitted and how much the other regular ratepayers are being disadvantaged. System Welfare does not depend on the tariff volumetric structure.

Conclusions

Integration of PV prosumers in the market is generating cross-subsidization among customers benefitting more those prosumer with higher PV capacities, on the Free Market and under the Dual Rate tariff structure. In order to mitigate the avoidance of fixed costs from prosumers, the fixed component on the retail tariff must be increased to better reflect the system cost structure. Additionally, devaluing the retail energy price within the PV Production period would be another measure to mitigate cross-subsidization.

On the other hand, it can be concluded that integration of PV prosumers will generate in all cases a system loss of welfare.

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