Utilities Policy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Utilities Policy

journal homepage: www.elsevier.com/locate/jup

Self-supply and regulated tariffs: Dynamic equilibria between photovoltaic market evolution and rate structures to ensure network sustainability

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A R T I C L E I N F O

Keywords:
Self-supply
Regulation
Ratepayer cross-subsidy

A B S T R A C T

This research analyses the impacts of substantial changes in energy production driven by self-supply through Photovoltaic (PV) adoption. Three different regulatory design options are analysed with a model developed to estimate the evolution of self-supply deployment as a function of price by: (i) starting with the actual tariff structure and parameters; (ii) introducing a new network usage component for rate-payer energy suppliers, and (iii) evolving towards higher allowed revenues recovered through fixed charges under the tariff. The results of the analysis suggest that gradual transitions toward higher fixed Network Access charges do not dissuade PV deployment.

1. Introduction

Solar photovoltaic (PV) generation plays a marginal role in the Portuguese electrical energy system. IEA, 2015, it represented 1.6% of the total energy generation (755 MWh) and 2.3% of the total installed capacity in Portugal (429 MW) (REN Redes Energeticas Nacionais SGPS S.A, 2016). However, solar energy generation costs are expected to decrease (Brazilianet al, 2013; IEA, 2015; Nagy et al., 2013). Portugal is one of the European countries with the highest solar radiation availability (Solar, 2007), providing very good conditions for the deployment of solar PV. See Fig. 1 for generation typical output in a Winter, Spring, Summer, and Autumn day in Lisbon (Fonseca et al., 2017).

With such high solar radiation, distributed solar production is likely to increase, including PV self-supply by residential customers, which is still incipient in Portugal; 27,300 micro and small production units with a total installed capacity of 166 MW exist, with more than 99% being PV. The evolution of the number of micro and small production units is shown in Fig. 2 (Bastião, 2016). In Europe, half of the total installed PV capacity is associated with LV networks (Vandenberghet al, 2013).

We analyse the impact of a large injection of PV self-generation into low-voltage networks on the financial interests of different electrical energy agents. We simulate both the evolution of the installed PV capacity and the evolution of the electrical energy cost supported by ratepayers with PV and without PV modules installed (non-adopter ratepayers). The simulations are based on a model assessing the economic incentives associated with PV installation and the evolution of regulated tariffs.

The analysis is focused on normal low-voltage (NLV) ratepayers, which have a subscribed capacity up to 41.4 kV A (60 A per phase). Ratepayers with subscribed capacities higher than 41.4 kV A are termed Special Low Voltage (SLV). SLV users are priced differently and, given their high level of subscribed capacity, are usually powered by a dedicated cable directly connected to the secondary substation.

In Portugal, regulated tariffs remunerating energy as well as transmission and distribution network costs are mostly based on volumetric charges, particularly for LV ratepayers (ERSE, 2014a; ERSE, 2014b). Since fixed costs are partially remunerated through volumetric charges, self-supply can be suggestive of cross-subsidies and related policy issues. Even though self-supply contributes to the dissemination of renewable energy production, it can transfer wealth from the less affluent to the more affluent consumers (Brown and Bunyan, 2014), or from conventional consumers to prosumers (Picciariello et al., 2015). One principle associated with two-part tariffs is some assurance that the fixed component covers development costs[2] or long-term marginal costs, associated with long-term investments needed to adapt system capacity to demand, and the variable component covers marginal costs. This definition is presented by Boiteux (1956, 1960). Self-supply units allow their owners to reduce the quantities paid through the variable

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[2] Or long-term marginal costs, associated with long term investments that guarantee that the system capacity is perfectly adapted to demand. This definition is presented by Boiteux in (Boiteux, 1960).

https://doi.org/10.1016/j.jup.2017.11.004
Received 7 July 2017; Received in revised form 26 November 2017; Accepted 26 November 2017

Abbreviations

CMEC Contractual Equilibrium Costs
DSO Distribution System Operator
FiT Feed-in Tariff
GSU Global System Use tariff
HV High Voltage
LV Low Voltage
MV Medium Voltage
NLV Normal Low Voltage
PPA Power Purchase Agreements
PV Photovoltaic
SLV Special Low Voltage
TSO Transmission System Operator
VAT Value-Added Tax

Nomenclature

$b_{i,j}$ Annual cost associated with Network Access charge (bi-hourly option) and energy costs for $C_{i,j}$ (€)
$s_{i,j}$ Annual cost associated with Network Access charge (single hour option) and energy costs for $C_{i,j}$ (€)
$thr_{i,j}$ Annual cost associated with Network Access charge (thrice-hourly option) and energy costs for $C_{i,j}$ (€)
$C_{s\text{-}c,m}$ Compensation paid in month *m*, per kW of installed capacity, allowing to recover energy policy costs associated with Global System Use charge, (€)
CC Capital Cost of a PV rooftop system (€/kW)
$C_{i,j}$ Each element of a matrix representing rate-payers with a given subscribed capacity *i* and standard deviation from the average consumption level, j (kWh)
$C_{i,j}^h$ Represents the load diagram associated with rate-payer $C_{i,j}$ for each period *h*, with 15-min resolution ($C_{i,j}^h = [C_{i,j}^1 ... C_{i,j}^{35040}]$), (kWh)
D Demand (electrical energy consumption)
$Epc_{i(t-n)}^p$ The sum of the costs associated with CMEC assigned according with the voltage level to which a self-supply unit is connected, for year *t-n* (€/kWh)
$Epc_{i,h(t-n)}^p$ The sum of the arithmetic average of the value, for different *h* hourly periods, of the costs of general interest (other than CMEC) associated with CMEC assigned according with the voltage level to which a self-supply unit is connected, for year *t-n* (€/kW)
$E_{s,m}$ Energy supplied to the network during month *m* (kWh)
LC Levelised Cost of a rooftop PV system (€/kW/year)
K_t Coefficient to be applied to $V_{cost,t}$ depending on the total self-supply installed capacity connected with the Portuguese electrical system in year *t*
N Existing number of NLV clients
N_{PV} Number of clients expected to install PV systems
$OMIE^h$ Value of the electricity price in the spot market for Portugal, on the hour *h* (€/kWh)
NA_{bi} Cost associated with Network Access charge (bi-hourly option) (€/kWh)
NAs Cost associated with Network Access charge (single hour option) (€/kWh)
NAthr Cost associated with Network Access charge (single thrice-hourly option) (€/kWh)
URD_{bi} Cost associated with Use of Distribution Network charge (bi-hourly option) (€/kWh)
URDs Cost associated with Use of Distribution Network charge (single hour option) (€/kWh)
URDthr Cost associated with Use of Distribution Network charge (single thrice-hourly option) (€/kWh)
$OMIE_m$ Arithmetic average value of the electricity price in the spot market for Portugal, on the month *m* (€/kWh)
p_0 Cost of a PV module in year 0 (initial cost of a PV module) (€/kW)
p^t Cost of a PV module in year *t* (€/kW)
p_{s-c} Stipulated capacity of the self-supply unit, (kW)
Q Relation between the price of a PV module in year t and in year *t+1* (p^{t+1} / p^t)
r Discount factor (%)
R_f Total fixed remuneration yielded by Network Access charges (€/year)
R_v Total variable remuneration yielded by Network Access charges(€/year)
R_t Total remuneration yielded by Network Access charges (variable + fixed) (€/year)
$R_{s\text{-}c,m}$ Remuneration of the energy supplied to the network by a self-supply unit, during month *m* (€)
$SC_{i,j}$ Optimal installed capacity of self-supply units associated with ratepayers $C_{i,j}$ (kW)
$V_{cost,t}$ The value of energy policy costs to be recovered through self-supply units (€/kW)

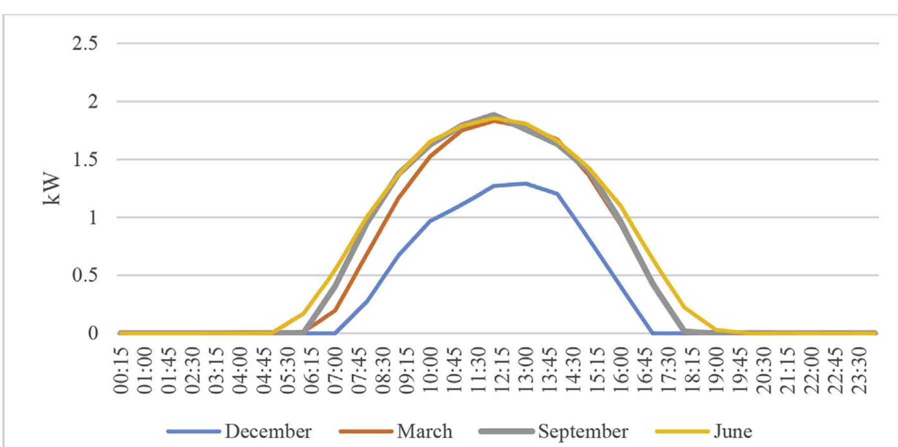

Fig. 1. PV typical load production programs for PV systems installed in Lisbon, with 2.5 kW installed capacity and assuming 1810 h (Fonseca et al., 2017).