Renewable and Sustainable Energy Reviews 77 (2017) 706–717

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Hidden financial implications of the net energy metering practice in an isolated power system: Critical review and policy insights

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A R T I C L E I N F O

Keywords:
Distributed PV generation
Net energy metering
Prosumers
Use-of-system cost recovery

A B S T R A C T

This paper provides useful insights regarding the financial implications of the currently applied Net Energy Metering (NEM) practice in Cyprus through analyzing the implemented policy under: a) the customers' perspective and b) the utility (Electricity Authority of Cyprus) perspective. These two perspectives are known in the scientific literature as the *participant cost test* and the *utility cost test* respectively. Within the paper, the financial analysis from the customers' perspective, it embraces the impact resulting from a series of factors influencing the viability of net-metered PV systems' investments. Furthermore, the analysis from the utility's perspective relates to the expected costs and benefits that EAC may experience due to the current NEM rules and applied charges. Finally, the key findings pertaining to the current NEM policy's hidden financial and policy implications are critically discussed. This discussion is performed to facilitate a more diligent NEM policy that will allow further penetration of roof-top PV systems through well-informed and transparent decisions.

1. Introduction

Net metering (NEM) is an alternative policy to traditional Feed-in Tariffs (FiTs) for the compensation of distributed generation (DG). The key difference between the two schemes is that NEM works through retail tariffs, thus allowing retail customers to offset their electricity bills via the utilization of their privately owned generating system [1]. Net-metered photovoltaic (PV) investments are gradually becoming popular amongst residential customers due to the simplicity of NEM scheme. Under this scheme the customers' consumption is directly coupled to the energy yielded from their privately-owned PV unit. Thus, it provides a relatively understandable form of repaying their investment by virtue of their reduced retail electricity consumption charges. Even though NEM is appealing due to its relatively unpretentious form, there exist: a) different implementation schemes and b) concerns regarding its long-term sustainability amongst stakeholders at an international level.

The main NEM implementation schemes are shown in Fig. 1 [2]. Specifically, Fig. 1-(a) illustrates the use of a single bidirectional meter that keeps record of the cumulative amounts of imported and exported energy. The implementation shown in Fig. 1-(b) relies on the use of two separate, unidirectional meters (one measuring the customer's consumption and the second measuring the customer's PV generation). Lastly, the NEM implementation shown in Fig. 1-(c) utilizes two separate meters, one bidirectional and one unidirectional that measure the import/export energy and PV energy respectively. An important subtlety regarding the third configuration lies in the fact that it allows utilities to keep record of the exact amount of PV energy that is self-consumed behind-the-meter of the NEM customer. Conversely, the other two configurations are not able to keep an explicit record of the self-consumed PV energy. Depending on the objectives of the regulatory authorities, this extra information may be needed in the electricity billing or taxing processes.

It should be noted that the most widely adopted metering implementation is the one shown in Fig. 1-(a). The second metering implementation is usually utilized in cases where the customer's consumption is charged entirely through the retail tariff whilst the PV generation is compensated at a different rate (either lower or higher). This kind of arrangement decouples the two energy amounts (i.e. consumption and PV generation) and, to this extent, it is similar to how a regular distributed generator would receive compensation through a Feed-in Tariff scheme. Finally, the third metering implementation is utilized in cases where the self-consumed and exported PV energy are treated differently in the electricity billing processes and/or the total consumption of a NEM customer must be known to the utility.

The arising concerns regarding NEM implementation mainly pertain to the traditional business model of regulated utilities. This

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http://dx.doi.org/10.1016/j.rser.2017.04.032
Received 15 September 2016; Received in revised form 4 April 2017; Accepted 17 April 2017
Available online 02 May 2017
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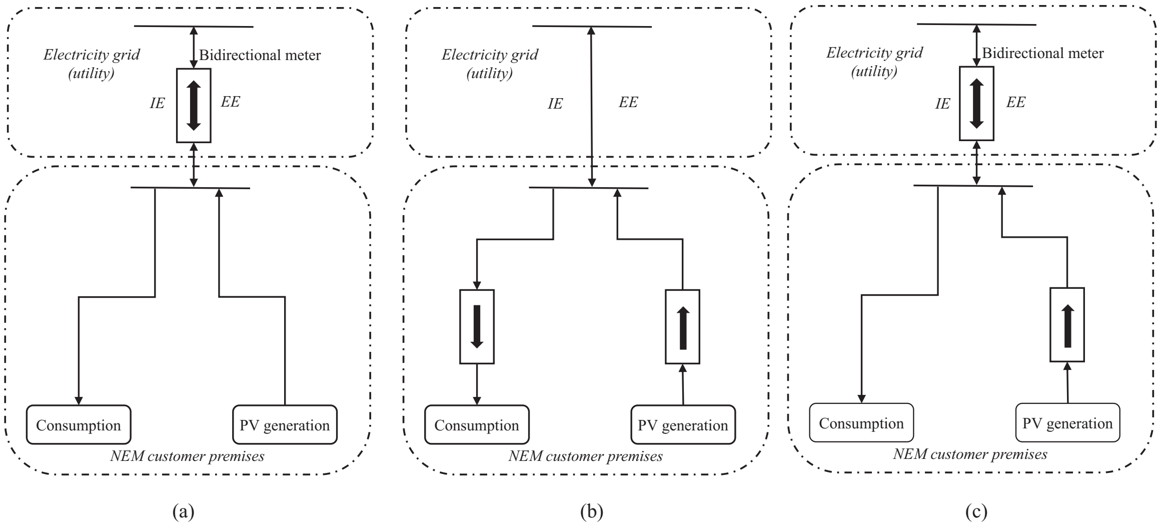

Fig. 1. Metering implementation of NEM [2].

business model has been based on volumetric retail rates. That is, customers are (implicitly or explicitly) charged based on their total consumption volume (i.e. kWh). However, volumetric rates usually include both fixed (i.e. the costs that do not vary with the generation output) and variable utility costs [3–5] thus having the potential of creating significant revenue gaps [6–12] when inflexibly applied in NEM schemes. The latter is an ongoing debate in several countries that have adopted NEM schemes and is reflected on relevant studies relating to alternative NEM mechanisms (e.g., Value of Solar Tariffs [13–15]). Value of Solar Tariff, in particular, is a mechanism that could potentially better reflect on the various cost components that are included in retail tariffs, thus aiming to minimize the revenue gaps that may appear as PV penetration increases to significant levels.

To this extent, it should be noted that there exists an inherent connection between utility revenue stability, net-metered customers and regular customers which is dictated by the inherent nature of retail rate design. This has been decorously discussed in relevant research works [16–19]. In simple words, if price signals are not correctly reflecting the true costs and benefits associated with the evolution of the grid to a more heavily PV penetrated system; the arising revenue imbalances will affect the rest of the customer base. For example, if NEM compensation is set too high, then utilities are bound to face revenue gaps that will weaken their financial status and their future ability to consistently remain in the electricity business. To restrain such an effect, utilities may choose to recover these lost revenues through elevating electricity rates for their entire rate base. This creates a direct cross-subsidy from regular customers to solar ones. This raises fairness concerns and has the potential of leading into the electricity rate death spiral [7,16,20,21]. On the other hand, if NEM compensation is set too low, then the investment incentive is effectively reduced, thus hindering future PV penetration [8]. It is, therefore, crucial for utilities and regulatory authorities to provide the correct price signals to customers (and potential investors) for two very important reasons [22,23]. The first reason pertains in ensuring as much as possible a “least-cost” system expansion and, therefore, minimum prices and the second (and perhaps most important reason) to maintain a high level of stature and credibility in the process, in order to assure retail customers that their exposure to regulatory risks is minimum.

1.1. Specific contributions of this work

This work focuses on providing policy insights regarding NEM policies via an in-depth overview of the current NEM practice that has been adopted in Cyprus since June 2013. Firstly, a concise description of the market organization in Cyprus is provided in order to provide a background context in the subsequent analyses. To this extent, the NEM effects are examined both from the customers’ as well as from the utility's perspective. Based on the results of this examination, a critical review of the currently adopted charging mechanism for NEM customers is performed. Particular emphasis is given on each cost component of the regulated use-of-system (UoS) charges, which largely reflect the fixed utility costs. We discuss how these are currently recovered from NEM customers and, consequently, how they affect the final collectable revenue of the whole system's fixed costs. Consequently, the hidden financial implications associated with the implemented NEM practice are revealed. As a final note, the paper presents an alternative, applicable NEM practice that may substitute the currently adopted NEM practice in Cyprus. This alternative NEM practice takes into account the interaction of NEM customers with the grid. The alternative practice is investigated for two important reasons: a) firstly, its implementation is based on the use of the same metering infrastructure that is currently utilized in Cyprus, and, b) it is directly compatible with the traditional, volumetric model of UoS cost recovery. To this extent, the alternative NEM practice proposed would treat all customers, regular and NEM, consistently. Hence, the proposed approach can be perceived as an unbiased UoS charging framework in terms of both DG and energy efficiency investments [24–27].

2. Background information

2.1. Brief description of the market organization in Cyprus

The market organization that applies in Cyprus (see Fig. 2) is

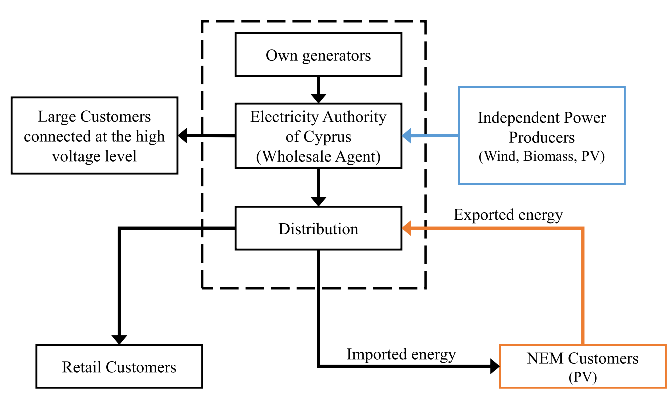

Fig. 2. Current market organization in Cyprus.

known in literature as the "purchasing agent" market organization model [28]. That is, a single entity (i.e. the wholesale agent) is responsible for reliably producing/procuring adequate electricity amounts either from its own generators or from independent power producers (IPPs) to serve its customers' base. The power system in Cyprus is characterized as a small, electrically isolated system with an almost exclusive dependence on oil products (mainly Heavy Fuel Oil and distillate Diesel Oil) for its electricity generation. All conventional (i.e. fossil-fueled) generators are owned by the Electricity Authority of Cyprus (EAC) which acts as both the wholesale agent and the distribution system operator (DSO). Furthermore, there exists a number of IPPs with wind, biomass and PV generating systems that are compensated through FiT schemes and, from 2013 onwards, NEM customers with roof-top PV systems are gradually being integrated at the low voltage level of the Cyprus distribution network.

It is also noted that the retail market in Cyprus operates under a traditional regulated regime whereby EAC acts as the sole load serving entity for all customers. For residential customers in particular, the current regulatory approach relies on a price-capped tariff (see, for example, [4,5,29–31]) resulting from the long-run marginal costs of EAC for providing electricity services. An example of long-run marginal cost calculation can be found in [32]. This price-cap is re-evaluated and adjusted approximately every 5–10 years. Under this approach, EAC bears all the actual costs of serving the system's load (i.e. demand plus losses) but receives compensation through a standard (i.e. price-capped) retail tariff. Therefore, in case where the actual incurred costs of EAC are less than the anticipated revenue through the price-capped tariff, the difference is kept by EAC as gained profit. Conversely, when the actual costs exceed the final revenue, then EAC is financially penalized. Nevertheless, when a retail tariff adjustment takes place, the actual financial profits or losses of EAC are taken into account by the Cyprus Energy Regulatory Authority (CERA) in order to ensure that actual EAC costs and revenue are closely aligned and that large deviations are averted [33].

More specifically, the vast majority of residential customers in Cyprus are charged through the EAC Domestic Tariff 05 (EAC05) which is a smoothly increasing, five-tiered, volumetric tariff. Thus, EAC's revenue mechanism from residential customers is a function of the final sales (in kWh). The details of EAC05 are provided in Table 1 below [34].

It is also important to clarify that EAC incurs both variable and fixed costs when producing, transmitting and distributing electricity to its customers. In general, variable costs are a direct function of the final energy produced and they mainly reflect on the fuel costs that have to be borne by the system. Conversely, fixed costs do not vary with the final output and they mainly reflect on the necessary capital and maintenance costs associated with generation, transmission and distribution facilities that are necessary to fulfill the capacity requirements of the utility. These fixed costs are commonly defined as UoS charges and they are presented in Table 2 [35].

Table 1
Description of the EAC domestic tariff 05 (EAC05) [34].

Tier	Total Bimonthly Consumption (kWh) – X	Per unit charge (€/kWh) – EC	Customer charge (€/billing period) – CC
1st tier	0–120	0.1371	2.28
2nd tier	121–320	0.1453	2.35
3rd tier	321–500	0.1498	3.86
4th tier	501–1000	0.1541	5.87
5th tier	1000+	0.1558	7.39
Other charges (€/kWh)			
Fuel adjustment clause – FAC	([Current Brent Price in €/MT]–300) × 0.000238		
Public Service Obligations – PSO	0.00134		
RES fund – RES	0.005		
VAT rate	19%		

2.2. Current NEM implementation in Cyprus

Fig. 3 illustrates the metering infrastructure currently deployed in Cyprus for NEM customers. This infrastructure relies on the use of a single bidirectional meter that is able to keep record of the cumulative amounts of both the imported and the exported energy.

The NEM scheme is currently available only to domestic (i.e. residential) customers via an energy credit compensation mechanism. The details of this scheme are listed below:

- NEM customers are charged through EAC05 (see Table 1) which is an increasing, five-tiered, volumetric tariff designed for domestic customers.
- The maximum allowable installed PV capacity per customer was initially set at 3-kW_p and it has recently been reset at 5 kW_p.
- At the end of each bimonthly billing period, the NEM customer pays for the difference between the consumed and generated energy (i.e. net energy consumption).
- In case there is excess of PV energy generation, the energy amount is rolled-over to the next billing period to offset future energy consumption.
- At the end of each 12-month billing cycle, any remaining energy credits are set equal to zero (i.e. they cannot be transferred over to the next year).
- Each NEM customer is required to pay a series of UoS charges as per the rated capacity of the PV system.

The details of the charges applicable to NEM customers are shown in Table 3. These charges are imposed on NEM customers based on the rated capacity (kW) of their installed PV systems. In particular, these UoS charges include a fraction of the cost components shown in Table 2. Additionally, NEM customers are facing: a) an extra charge for the time diversity between prosumers' PV generation and actual consumption and b) an extra credit for reducing the power losses of the supplying network. It should, nevertheless, be noted that these charges as well as the losses' credit are regarded as interim. This was explicitly highlighted in the directive of CERA in July 2013 [36].

2.3. Customers' perspective towards the current NEM practice in Cyprus

For Cyprus in particular, current as well as prospective NEM customers (i.e. prosumers) should bear in mind the following elements when assessing the viability of their net-metered PV systems' investments:

- Fundamentally, the payback period of the PV net-metered investment, should result from the comparison of the present value of savings (i.e. cash flows) that would be encountered in a customer's bimonthly electricity bills –over the expected life time of the PV system installed– to the initial investment capital costs.

  Moreover, specific factors that impact on their bill savings and thus on the payback period of their PV net-metered investments are:
  - Initial PV capital costs, annual operation and maintenance costs, solar potential (i.e. PV Levelised Cost of Electricity (LCOE)).
  - Type and structure of retail tariffs (i.e. under which tariff the electricity bill of prosumers is based on – e.g. domestic EAC tariff 05).
  - Type and price of fuels used in the generation mix of the system in Cyprus.
  - Aggregate and time-related consumption profile of customers' households prior to the installation of PV systems.
  - Restrictions that apply on energy credits transfer and period at

Table 2
Approved UoS charges currently applying in Cyprus [35].

Use of system	Per kWh charge (€/kWh)	Description
Cyprus TSO	0.0009	Operating costs of the Transmission System Operator of Cyprus
Ancillary services	0.0024	Frequency (i.e. primary, secondary and tertiary reserves) and voltage support (i.e. reactive power management) services provided by EAC
Long-term capacity reserve	0.0053	Costs of providing an adequate reserve margin of installed generating capacity
HV system	0.0099	Network costs for the high voltage system
MV system	0.0153	Network costs for the medium voltage system
LV system	0.0169	Network costs for the low voltage system

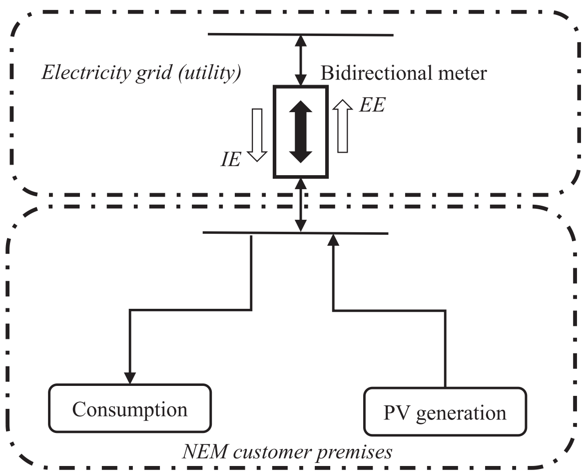

Fig. 3. Metering infrastructure for NEM customers in Cyprus.

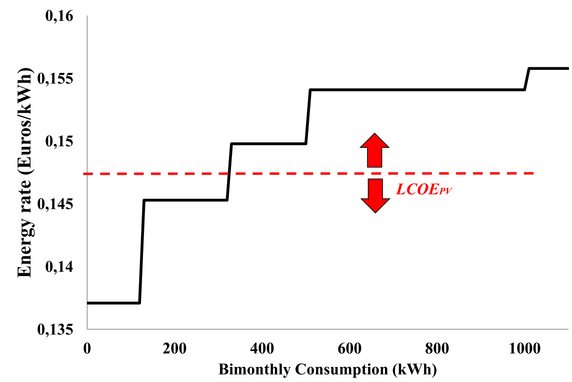

Fig. 4. Different customers will avoid different tiers of the EAC 05 tariff should they decide to adopt the NEM practice currently applied in Cyprus.

which any excess energy credit is dismissed (i.e. not transferred on to the next billing period).

- Discount rate used to determine the present value of future electricity bill savings.
- Extra charges (fixed or variable) that are imposed on NEM customers (e.g., CERA UoS charges – Table 3).

Primarily, towards assessing the financial viability of NEM investment, current as well as prospective NEM customers (i.e. prosumers) should appreciate the dynamics of the EAC Domestic Tariff 05 (EAC05). This tariff, charges residential customers and hence prosumers, for their energy use through a smoothly increasing-block rate. Due to the fact that EAC05 is an increasing-block rate tariff, different customers will avoid different tiers of the charges (see Fig. 4), should they decide to adopt the NEM practice currently applied. This means that larger consumers, who usually reach the higher tiers of EAC05, may face increased investment incentives. However, it should be thoroughly understood that a 5kWp PV system (i.e. the maximum PV capacity permitted for NEM applications) would not necessarily mean a more profitable investment, especially for small consumers. Thus, the PV capacity of a NEM system can be shown to have a non-proportional effect on prosumers' savings.

To holistically address the impact of all associated factors listed above, a sensitivity analysis through Monte Carlo simulations is undertaken in order to estimate the range of the payback period of a NEM investment. The aim is to provide an indication of the probability of the NEM investment being viable in Cyprus. Thus, the main parameters of the financial analysis are considered random variables and are, therefore, assigned a specified probability distribution function (PDF). The examined parameters include: a) the initial PV capital investment costs and b) the average energy yield of the PV system, c) the annual discount rate selection and d) the annual escalation rate of Brent fuel price. The relevant assumptions of the Monte Carlo simulations performed are given in Table 4 whilst the corresponding results are shown in Fig. 5. The number of simulations was set equal to 20,000 thus allowing the process to capture the whole range of possible combinations between the considered parameters. The Monte Carlo simulation results clearly indicate that an investment in a net-metered PV system in Cyprus is financially sound under most circumstances.

Table 3
Current charges and credits imposed on NEM Customers in Cyprus [36].

Use of system	Assigned percentage payable by NEM customers (%)	Per kWh charge (€/kWh)	Annual PV energy yield (kWh/kWy)	Payable amount (€/kWy)
Cyprus TSO	100%	0.0009	1610	1.48
Ancillary services	90%	0.0024		3.50
Long-term capacity reserve	18%	0.0053		1.53
HV system	25%	0.0099		3.98
MV system	50%	0.0153		12.31
LV system	75%	0.0169		20.41
PSO fund	100%	0.00134		2.16
RES fund	100%	0.005		8.05
Time diversity between PV generation and household demand	–	–	–	13.81
Power losses reduction credit	–	–	–	−20.00
Total	–	–	–	47.24

Table 4
Monte Carlo Simulation Assumptions.

Parameter	Mean value	Type of distribution	Standard deviation (%) – Range
Annual Consumption (kWh)	5220	Constant	–
PV Installed Capacity (kW_p)	3	Constant	–
Average Energy Yield (kWh/kWy)	1610	Normal	3%
Annual Discount Rate (%)	8%	Uniform	From 4% to 12%
PV Operation and Maintenance (€/kWy)	20	Constant	–
Initial Cost (€)	5000	Normal	5%
Brent Fuel Price (€/MT)	320	Constant	–
Annual Fuel Price Escalation Rate (%)	2%	Uniform	From −2% to 6%
Useful Lifetime (Years)	20	Constant	–

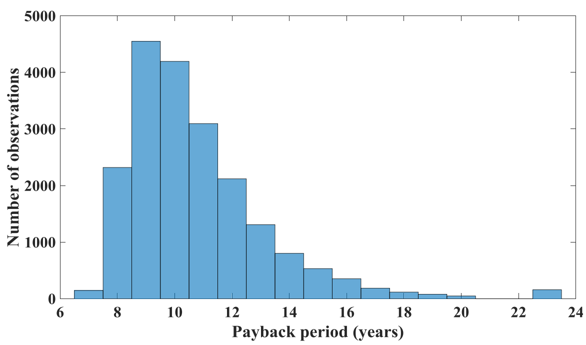

Fig. 5. Monte Carlo Simulation Results on Payback Period of NEM Investments in Cyprus.

Based on the simulation results (see Fig. 5), there is 50% probability that the payback period will be less than 10 years (under current NEM practice and relevant assumptions of Table 4). Moreover, there is less than 1% probability that such an investment will lead to net financial losses for the NEM customer. This implies that the PV system will generally generate adequate savings throughout its useful lifetime if current incentives persist in the future.

2.4. Utility perspective towards the current NEM practice in Cyprus

As discussed in the previous section, an investment in net-metered PV systems (under the applied terms and conditions) for domestic customers in Cyprus could be a viable option for curbing their electricity bills. However, the downward pressure in electricity sales that is imposed on EAC due to the currently applied NEM scheme is raising doubts regarding its long-term sustainability. That is, if penetration is to be increased further, EAC revenue streams may be significantly reduced. This may result in higher future electricity rates for the rest of EAC's customers. As noted in Table 3, the total annual payable amount that relates to the fixed costs of EAC sums up to €47.24/kWy. To this extent, the actual EAC revenue loss will be determined by two main factors: a) the cumulative installed PV capacity (i.e. total installed kW_p) and b) the type of customers (i.e. small, medium and/or large) that will invest in net-metered PV systems [37].

Today there exist approximately 430.000 domestic customers in Cyprus exhibiting an average annual consumption of 3500 kWh [37]. The sales of the domestic class of EAC customers sum up to 36% of the total annual EAC sales whilst the revenue collected sums up to 37.36% of the total annual EAC revenue. A thorough method for calculating the revenue loss that EAC experiences due to NEM penetration was elucidated in [37]. Based on the method described in [37], the 60 MW of NEM PV penetration (currently applied in the Cyprus Power System) results in approximately 7.80% reduction in the annual residential energy sales of EAC. That is, 6.30% of revenue loss.

3. Critical review of current NEM practice in Cyprus

EAC as a regulated utility solely operates and bears all the costs associated with procuring, maintaining and operating all necessary facilities and equipment in order to serve customers at an acceptable reliability level. One should appreciate, at this point that the cost recovery business model of EAC is that of traditional regulated utilities. It relies on volumetric (kWh) retail rates. Bearing in mind that the cost recovery business model of EAC is not envisaged changing in the near future, the main concern arising is that, the currently applied NEM practice in Cyprus may create significant and unjustified revenue gaps for EAC. The inherent characteristic of the volumetric business model of EAC is that it charges regular customers based on their grid-imported energy. This is not the case for NEM customers (i.e. prosumers) though, as it will be further discussed.

3.1. Reviewing currently applied charges and credits

Firstly, it is important to clarify that EAC incurs both variable and fixed costs when producing, transmitting and distributing electricity to its customers. In general, variable costs are a direct function of the final energy produced and mainly reflect the fuel costs that have to be borne by the system. Conversely, fixed costs do not vary with the final output and mainly reflect on the necessary capital and maintenance costs associated with generation, transmission and distribution capacity requirements.

To this extent, the charges shown in Table 3 are applied to NEM customers, in an attempt to recover a portion of the EAC's fixed costs. These charges are imposed on NEM customers based on the rated capacity (kW) of their installed PV systems. In particular, the cost components include: a) the TSO's fees, b) the ancillary services, c) the long-term reserve capacity, d) the use of high voltage network, e) the use of medium voltage network, f) the use of low voltage network, g) the Public Service Obligations (PSO) levy, and h) the Renewable Energy Sources (RES) fund.

The specifics of the current charges imposed on NEM customers are critically commented below:

1) **NEM customers pay 100% of the approved CERA charges for the TSO, PSO and RES fund:** These costs are neither deferrable nor avoidable for EAC. Thus, NEM customers cannot offer this kind of services to the system and, hence, the fact that these costs are recovered in full is justified.
2) **NEM customers pay 25%, 50% and 75% of the approved CERA charges for their use of the High Voltage (HV), Medium Voltage (MV) and Low Voltage (LV) system respectively:** These three cost components refer to the network equipment (i.e. lines, cables, transformers, etc.) that are required to serve the demand. It should be noted at this point that net-metered PV generation may postpone future, load-growth-driven investments (e.g., upgrading or purchasing network-related equipment [38,39]). However, these deferrals have to be carefully evaluated in order to reflect the true savings that EAC may experience in the long-term. To this extent, if the currently applied percentages do not precisely reflect on the actual EAC savings from NEM, then EAC is bound to face significant revenue gaps which will be inevitably and eventually passed to non-NEM customers.
3) **NEM customers are charged 90% of the approved CERA charges for ancillary services:** Ancillary services usually refer to spinning reserve services (i.e. primary, secondary and tertiary reserves) and voltage support (i.e. reactive power management) [28,40–42]. To this extent, these services mainly relate to the

necessary frequency and voltage variation management in order to ensure the reliable operation of the system at all times. Therefore, a thorough examination of the impact of variable PV generation on the requirements for such services for the isolated power system of Cyprus should be performed in order to undoubtedly justify the fact that NEM customers should be charged with a reduced fee.

4) **NEM customers are charged 18% of the approved CERA charges for long-term capacity reserves:** This is equivalent to assigning PV generation with an 82% capacity credit [6,43,44]. Even though Cyprus exhibits a very high solar potential which positively correlates with the system's demand, the capacity credit implicitly assumed (i.e. 82%) seems rather exaggerated. Moreover, due to the time-concentrated nature of solar technologies, their respective capacity credit is also dependent their relative penetration. For example, solar technologies are notorious for potentially causing the "duck curve" effect [45].
5) **NEM customers are charged €13.81/kWy for the time diversity between their demand and their PV generation:** This particular charge refers to the fact that NEM customers receive an extra service; that is the PV energy generated is not entirely self-consumed, i.e. there is time diversity between PV generation and consumption (e.g. from hour to hour, from day to day and from season to season). The electric grid accommodates time diversity through conventional, dispatchable generating units. These units bear certain fixed costs in offering this service. Therefore, NEM customers are charged for these fixed generation costs, minus that part of the fixed costs that is already reimbursed through the UoS charges (i.e. long-term capacity reserves). Moreover, based on EAC calculations, the time diversity charge sums up to €55.20/kWy for each kW of installed PV capacity. However, CERA approved a €13.81/kWy figure that is approximately 25% of the EAC calculated figure.

Based on the above facts and analysis, the need for reevaluating the current NEM charges and credits in Cyprus can be collectively summarized as follows:

- The current NEM policy embraces some mildly justified and not transparent charges to account for both the costs and benefits entailing from roof-top PV penetration.
- NEM customers are not charged or credited based on their individual interaction (imported/exported energy) with the grid, but instead, on the rated capacity (kW) of their installed PV system.
- NEM customers are credited €20/kWy for an alleged reduction their PV systems bring on overall system's losses.

  To comprehend the reevaluation that is dictated by the three fundamental issues quoted above, the following concepts should be thoroughly understood:
- How NEM customers are interacting with the grid?
- What is EAC's business model for cost recovery?
- How NEM practice and retail tariffs are associated?

3.2. The interaction of NEM customers with the grid

A NEM customer can generate electricity on site to offset his demand and deliver any excess electricity to the utility for an equal amount of electricity from the utility at other times. However, the implication is that when a NEM customer directly offsets one kWh of his consumption with self-produced PV energy, the current NEM practice in Cyprus treats this transaction as if the customer has exactly matched his consumption with his generation, even though the two may have taken place at a different time. To make the latter argument more explicit, an example of a NEM customer's interaction with the grid is shown in Fig. 6. Under this specific example, the customer's total consumption is 14 kWh. Thus, before installing PVs, the customer would draw 14 kWh from the grid and would be charged for the entire grid-imported energy through the respective retail tariff. Once the customer installs a PV system, thus becoming a prosumer, the NEM scheme allows him to offset his consumption volume with self-produced PV energy. As shown in Fig. 6, the customer's PV system generated a total of 14 kWh, 7 kWh of which were consumed behind-the-meter of the customer (effectively a 50% self-consumption ratio). The remaining 7 kWh were exported to the grid. However, to cover the demand at times when the PV system is not generating sufficient energy, the customer had to import 7 kWh from the grid. To summarize the interaction of this particular NEM customer with the grid we note the following:

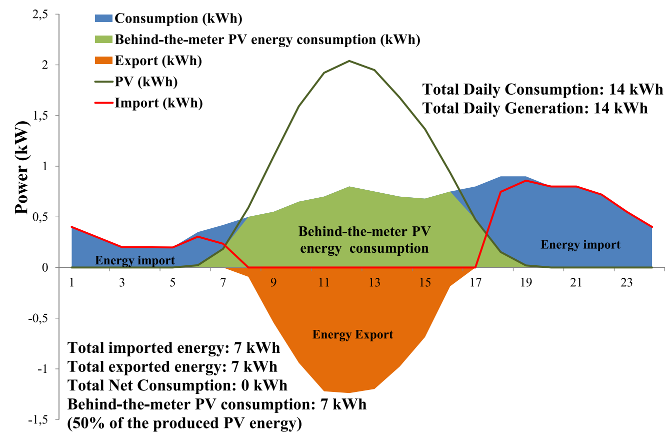

Fig. 6. Example of a virtually off-grid customer.

- The customer uses the grid to export excess energy (i.e. 7 kWh) at some time intervals within a day.
- The customer uses the grid to import needed energy (i.e. 7 kWh) at some time intervals within a day.

Thus, even though in this example the net difference between the customer's consumption and PV generation is zero (i.e. the customer appears to be virtually off-grid), the NEM customer interacts or uses the grid substantially for his import/export activities.

However, the currently applied UoS charges on NEM customers in Cyprus are decoupled from the interaction that each individual customer has with the grid. It is reiterated at this point that the current UoS charges are based on the installed kW_p of PV capacity of each NEM customer. To this extent, this method for recovering the UoS charges of NEM customers raises two very important questions:

a) Are the currently applied UoS charges truly reflecting the use of grid (i.e. import/export) by NEM customers'?
b) Since the metering infrastructure of NEM customers can keep track of both the imported and exported energy, why does the cost recovery rely on the installed PV capacity of NEM customers and not on their actual interaction with the grid, at least on a volumetric basis?

These questions inherently relate to the energy volumes that each NEM customer exchanges with the grid (i.e. the volume of exported kWh that was exchanged for the same amount of imported kWh). At this point, it should be mentioned that, in principle, any self-consumed PV energy remains within the customer's premise thus avoiding use of the network. By means of an example, however, if we were to relate the total amount of the currently payable UoS charges (i.e. €47.24/kWy) to NEM customers' grid interaction, then we would probably have to think as per the particulars shown Table 5. This Table attempts to theoretically benchmark the difference between the current UoS charges and the UoS charges that a NEM customer would face depending on how he exploits his produced PV energy (i.e. self-

Table 5
UoS payable amounts for different utilization of the produced PV energy from NEM customers.

Assumed PV generation (kWh/kWy)	Self-consumed PV Generation (kWh/kWy)	Exported PV generation (kWh/kWy)	UoS per kWh charge (€/kWh)	Annual UoS charges (€/kWy)	Current annual UoS charges (€/kWy)
1610 (100%)	0 (0%)	1610 (100%)	0.057	91.77	47.24
1610 (100%)	161 (10%)	1449 (90%)	0.057	82.59	47.24
1610 (100%)	322 (20%)	1288 (80%)	0.057	73.42	47.24
1610 (100%)	483 (30%)	1127 (70%)	0.057	64.24	47.24
1610 (100%)	644 (40%)	966 (60%)	0.057	55.06	47.24
1610 (100%)	805 (50%)	805 (50%)	0.057	45.89	47.24
1610 (100%)	966 (60%)	644 (40%)	0.057	36.71	47.24
1610 (100%)	1127 (70%)	483 (30%)	0.057	27.53	47.24
1610 (100%)	1288 (80%)	322 (20%)	0.057	18.35	47.24
1610 (100%)	1449 (90%)	161 (10%)	0.057	9.18	47.24
1610 (100%)	1610 (100%)	0 (0%)	0.057	0.00	47.24

consumed versus exported PV energy). The fundamental logic of this theoretical approach/example is that, due to NEM, a customer that exports a large amount of energy exhibits an increased use of the grid because he draws the same amount during other times thus imposing UoS costs on EAC. Conversely, a customer that exports small amounts of PV energy is directly offsetting his own consumption without using the grid.. The example in Table 5 explicitly shows that a customer that self-consumes all his PV generation would pay 0 €/kWy while a customer that exports all of his PV generated energy would pay 91.77€/kWy. Thus, under this theoretical approach the current UoS charges (i.e. €47.24/kWy) correlate with the UoS charges that a NEM customer with a 48.5% self-consumption ratio would be paying.

Nevertheless, it should be noted that EAC is ultimately interested in the average self-consumption ratio (SCR) of its NEM customers due to the fact that this average figure would determine the final collectable UoS revenue. In particular, as shown in Table 5, if NEM customers are forced to pay for their UoS charges based on their interaction with the grid, then the relationship between the payable UoS charges is linearly correlated with their SCR. Based on this fact, we consider the following two extreme scenarios: a) all NEM customers exhibit 50% SCR, and b) half of the NEM customers exhibit 0% SCR and the other half exhibit 100% SCR. Under the first scenario, all customers would pay €45.89/kWy and this would be multiplied by the total installed PV capacity to yield the final UoS revenue. Under the second scenario, half of the NEM customers would pay €0/kWy whereas the other half would pay €91.77/kWy. Thus, the final collectable UoS revenue would be 50%×€0/kWy+50%×€91.77/kWy, which again yields an average €45.89/kWy. This example explains why EAC is merely concerned on the average SCR of its NEM customers. However, the second example used above implies that when NEM customers are required to pay the same charges regardless of their interaction with the grid, then customers with high SCR subsidize those with low SCR. This is graphically illustrated in Fig. 7 through a hypothetical SCR distribution of NEM customers. It is, therefore, noted that the current NEM practice in Cyprus entails a hidden cross-subsidy. Thus, it is not far from reality to state that the current UoS charging method does not provide effective incentives for promoting self-consumption as a more efficient overall system operation.

3.3. Discussion on power losses credit

Of particular note is the fact that CERA has attributed a €20/kWy credit to NEM customers for an alleged reduction they bring in system losses. The premise of this credit is probably the fact that such DG applications not only act as sources of energy but can potentially reduce the overall losses in system networks [46]. It is often argued that a kWh produced by DG has a higher "value" than a kWh generated at the transmission level by a conventional central generating plant [46].

The power loss credit has been estimated as shown in (1). The elements used in (1) are thoroughly described in Table 6.

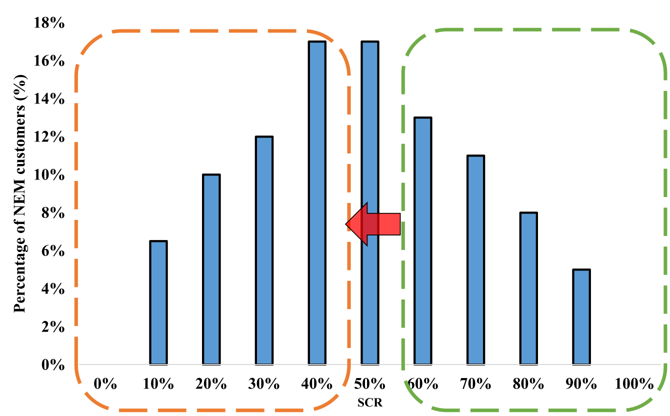

Fig. 7. Cross-subsidy between NEM customers with high SCR to NEM customers with low SCR.

$$\text{Power losses credit} = (\text{Loss Factor}) \times (\text{Cost of losses}) \times (\text{PV generation}) \tag{1}$$

In order to explicitly calculate the power losses credit to NEM customers, all three elements noted in Table 6 are required. Firstly, the loss factors applying for the system are needed. These are shown in Table 7. It is re-iterated that the loss factors are usually determined based on relevant calculations pertaining to the losses incurred at each stage of the system. To this extent, they are subsequently compounded in order to appropriately charge customers based on their point of connection (i.e. high, medium or low voltage level).

Successively, the cost of losses (as defined in Table 6) is needed. This figure should reflect the cost that EAC incurs in order to supply an extra kWh of losses. It is, thus, a figure that, in some extent, resembles the EAC avoided cost. Therefore, following the fundamental logic of (1), the power losses credit is calculated based on the annual PV energy yield (i.e. 1610 kWh/kWy). The €20/kWy figure calculated by CERA relies on a €0.1553/kWh cost of losses which is the EAC energy cost component for a €600/MT Brent fuel price. This figure was true during 2013, when the Brent fuel price was equal to €600/MT and the NEM UoS charges were calculated.

$$\begin{aligned}\text{Power losses credit} &= (8\%) \times (0.1553\ \text{Euros/kWh}) \times (1610\ \text{kWh/kWy}) \\ &= 20\ \text{Euros/kWy}\end{aligned} \tag{2}$$

3.3.1. Should (and how) NEM PV energy receive the credit for power losses reduction?

Having shown the estimation of the power losses credit for NEM customers from CERA, there is a consequent need to examine its validity and further how (and if) this should be credited to NEM customers bearing in mind, that NEM is a billing mechanism for

Table 6
Parameter definition for power losses credit calculation from CERA.

Loss Factor (LF)	It is a common practice for utilities to evaluate the losses incurred at each level of their systems in order to charge their customers in an appropriate manner. The latter is generally taken into account via the use of loss factors. Loss factors (LFs) are scaling factors applied at certain metering points to account for network losses. They are used in the calculation of network charges to recover the loss cost of the system. Utilities normally define LFs in accordance to the voltage level at which the load/generation is connected, and those values are used throughout the utility's jurisdiction [46]
Cost of Losses	Utilities and regulatory authorities are interested in losses since they cause an extra expenditure when serving the overall system's demand. To this extent, minimizing losses can potentially lead into significant cost savings in power systems' planning and operation endeavors. To make this argument more explicit; if losses are seen as an extra load to the system, it is apparent that sufficient system capacity should be required to accommodate the peak load plus the associated losses. This entails that the installed capacity requirements of a system are determined by the system's peak demand including its peak load losses. Hence, the costs of the additional capital and other fixed expenditures sized to supply the power used by the losses (coincident with the peak demand) constitute the demand component of the cost losses. However, when evaluating the total cost of losses in a network, one should also consider the energy component of the cost of losses. The energy component of the cost of losses comprises the variable costs of generating the additional energy consumed by the losses in all affected system categories (e.g. generation, transmission and distribution) [47,48].
PV Generation	This parameter reflects the annual energy yield per installed kW of PV capacity and is assumed equal to 1610 kWh/kWy [36].

Table 7
Loss factors for customers at each voltage level of the Cyprus power system.

Voltage level	
High Voltage (T3)	1.90%
Medium Voltage (T2)	2.50%
Low Voltage (T1)	3.40%
HV Customers	
Loss factor (1+T3)	1.0190
MV Customers	
Loss factor (1+T3)(1+T2)	1.0445
LV Customers	
Loss factor (1+T3)(1+T2)(1+T1)	1.0800

Table 8
Revised power losses credit calculation based on exported PV generation.

Assumed total PV generation (kWh) – X+Y	Self-consumed PV generation (kWh) – X	Exported PV generation (kWh) – Y	Power losses credit (€) – Y×COL×LF_{LV} COL=€0.1553/kWh LF_{LV}=0.08
1610 (100%)	0 (0%)	1610 (100%)	20.00
1610 (100%)	161 (10%)	1449 (90%)	18.00
1610 (100%)	322 (20%)	1288 (80%)	16.00
1610 (100%)	483 (30%)	1127 (70%)	14.00
1610 (100%)	644 (40%)	966 (60%)	12.00
1610 (100%)	805 (50%)	805 (50%)	10.00
1610 (100%)	966 (60%)	644 (40%)	8.00
1610 (100%)	1127 (70%)	483 (30%)	6.00
1610 (100%)	1288 (80%)	322 (20%)	4.00
1610 (100%)	1449 (90%)	161 (10%)	2.00
1610 (100%)	1610 (100%)	0 (0%)	0.00

treating exported generation from NEM customers. To this extent, if NEM customers' PV generation is treated as per the fundamental logic that dictates how DG applications are treated, then the compensation for losses would be based on the EAC true cost of losses that accounts for the exported PV generation. To clarify this argument, Fig. 8 shows the fundamental logic of how NEM PV generation could be treated under the same principles that apply for regular DG applications.

Under the logic in Fig. 8, Table 8 demonstrates the power losses credit that would be assigned to the exported PV generation of a NEM customer based on his interaction with the grid (i.e. self-consumed versus exported PV generation).

It should be re-iterated at this point that losses-related expenditures are recovered from EAC through appropriately elevated energy charges (i.e. €/kWh) based on a series of loss factors embedded in retail tariffs. Therefore, a portion of the charges faced by retail customers (i.e. EAC tariffs) relates to the losses incurred in order to serve them. Since NEM works through retail tariffs, it should be made clear that when NEM customers offset one kWh of their consumption with one kWh that was generated from their privately owned PV system, the retail rate that they avoid already includes the losses-related expenditures of the utility through the embedded loss factor the retail tariff embraces. In other words, NEM customers are rewarded for their contribution in reducing losses through the retail rate that they are allowed to offset. Thus, the extra CERA-assigned credit to NEM customers for their loss reduction contribution may result in crediting prosumers twice for the same benefit they bring to the system.

The above facts raise the following fundamental questions:

- *Since each kWh that a NEM customer offsets already includes the EAC losses-related costs (through the respective loss factor of the low voltage level), is it logical to include an extra loss credit figure?*
- *If so, shouldn't the loss credit correspond merely to the exported PV generation of each NEM customer?*
- *And, finally, what is the true cost of losses and how can this be calculated?*

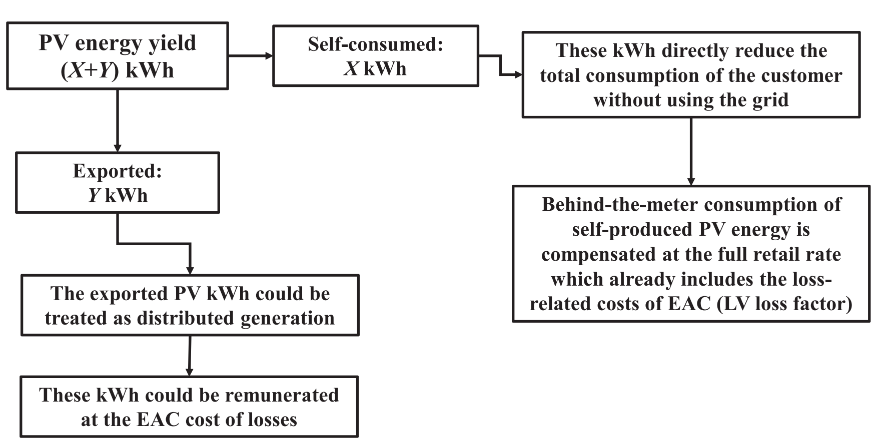

Fig. 8. Fundamental logic of treating NEM PV generation.

Table 9
Dependency of PV applications contribution to each EAC cost component.

EAC cost component	Dependency
Generation demand component	Capacity credit of the PV system
HV demand component	Peak load reduction at the HV level due to the PV generation relative coincidence with the peak HV demand
MV demand component	Peak load reduction at the MV level due to the PV generation relative coincidence with the peak MV demand
LV demand component	Peak load reduction at the LV level due to the PV generation relative coincidence with the peak LV demand
Energy component	Energy yield of the PV system
Loss factor	Connection voltage level

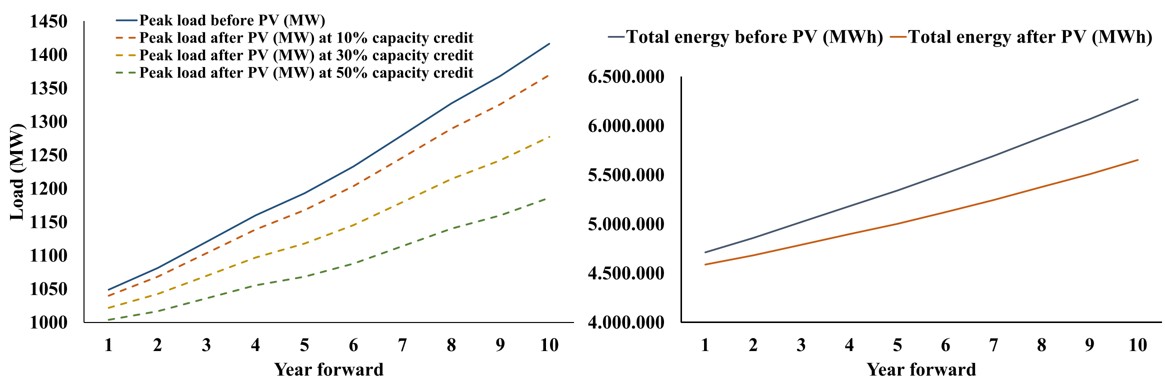

Fig. 9. Example of the potential effect of NEM PV on the system's peak load and final energy production requirements.

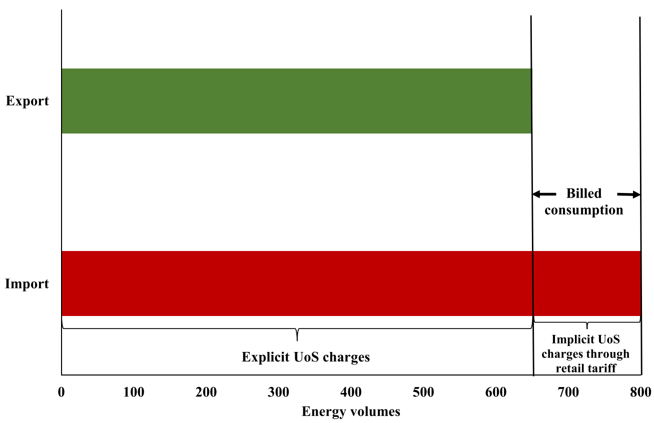

Fig. 10. Graphical illustration of the alternative NEM billing process.

3.3.2. How is the EAC cost of losses affected by the penetration of NEM PV?

The EAC cost of losses should embrace all fixed and variable costs incurred in order to supply an extra kWh of losses. To this extent, EAC's 10-year expansion plan is taken into account in order to calculate the demand and energy component of each system level. This has been thoroughly addressed in previous work (see [47] for a detailed formulation). However, it is imperative to examine how the EAC cost of losses is affected by net-metered PV systems as they progressively penetrate the system. More specifically, each cost component that EAC incurs may be affected by a different degree depending on the characteristics of PV generation and system's demand. Thus, the demand and energy component of the EAC cost of losses would have to be adjusted accordingly; bearing in mind the PV contribution on the reduction of each EAC cost component. This dependency is briefly described in Table 9 below.

By means of an example, the varying effect of PV penetration due to different relative capacity credit allocation is shown in Fig. 9, along with its effect on the final EAC energy production. The relative capacity credit is defined as the ratio between the reduction in conventional installed capacity requirements achieved (due to the PV penetration) over the total installed PV capacity whilst maintaining the same level of reliability. Thus, it is clear that NEM PV changes the costs incurred in serving demand and, to this end, its effect on the various cost components should be taken into account in a meticulous manner if penetration is to reach the envisaged levels without creating financial imbalances. The latter suggests that the current NEM practice in Cyprus may have to be revised in order to improve the compensating framework of PV applications and, thus, ensure their reliable financial integration and facilitate further penetration.

As a concluding remark we note that NEM is considered an easily implementable policy due to its simplicity and due to the fact that it requires minimal infrastructure upgrades in terms of metering. However, it is also notorious for bringing huge cross-subsidies between different groups, i.e. regular customers and prosumers that are benefiting from the fact that NEM compensation policies value energy output at the full retail rate. Nevertheless, there is no readily

Table 10
Example of the alternative and current NEM billing process for a NEM customer with a 3-kW$_p$ PV system.

Parameter			Calculation	Alternative practice	Current practice
Imported energy (kWh)	A	Measured	–	800	800
Exported energy (kWh)	B	Measured	–	650	650
Net consumption (kWh)	C	Calculated	A – B	150	150
Energy credit (kWh)	D	Calculated	max{−C,0}	0	0
Billed consumption (kWh) through EAC05	E	Calculated	max{C,0}	150	150
Extra UoS charges (€)	F	Calculated	(A – E)×0.057×1.19	€44.09	3×7.87×1.19= €28.10
Power losses credit (€)	G	Removed	0	€0	
Time-diversity charges (€)	H	Calculated	(A – E)×(13.81/1610)×1.19	€6.63	

Table 11
Comparison of the alternative and the current UoS cost recovery practice in Cyprus.

PV generation (kWh/kWy)	Self-consumed PV Generation (kWh/kWy)	Exported PV generation (kWh/kWy)	UoS per kWh charge (€/kWh)	Annual UoS charges (€)	Power losses credit (€)	Time diversity charges (€)	Current annual UoS charges (€)	Difference (€)
1610 (100%)	0 (0%)	1610 (100%)	0.057	91.77	0	13.81	47.24	−58.34
1610 (100%)	161 (10%)	1449 (90%)	0.057	82.59	0	12.43	47.24	−47.78
1610 (100%)	322 (20%)	1288 (80%)	0.057	73.42	0	11.05	47.24	−37.23
1610 (100%)	483 (30%)	1127 (70%)	0.057	64.24	0	9.67	47.24	−26.67
1610 (100%)	644 (40%)	966 (60%)	0.057	55.06	0	8.29	47.24	−16.11
1610 (100%)	805 (50%)	805 (50%)	0.057	45.89	0	6.91	47.24	−5.56
1610 (100%)	966 (60%)	644 (40%)	0.057	36.71	0	5.52	47.24	5.01
1610 (100%)	1127 (70%)	483 (30%)	0.057	27.53	0	4.14	47.24	15.57
1610 (100%)	1288 (80%)	322 (20%)	0.057	18.35	0	2.76	47.24	26.13
1610 (100%)	1449 (90%)	161 (10%)	0.057	9.18	0	1.38	47.24	36.68
1610 (100%)	1610 (100%)	0 (0%)	0.057	0.00	0	0.00	47.24	47.24

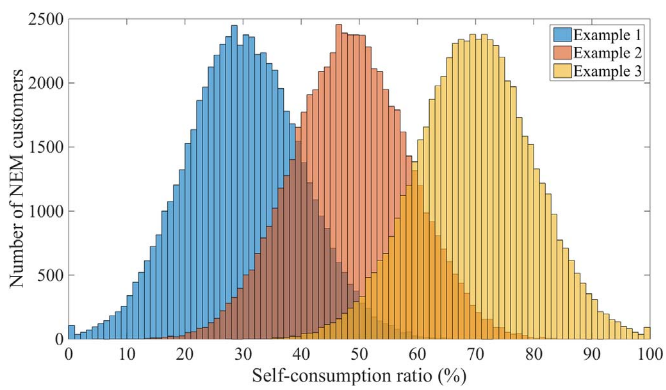

Fig. 11. Examples of different SCR distributions.

Fig. 12. Impact of average SCR on the final collectable UoS revenue under the alternative practice compared to current NEM practice.

implementable solution that eliminates all cross-subsidies. This is so due to several limitations that apply in this process; for example, the legacy metering and monitoring infrastructure, especially at the distribution level, effectively acts as a hard constraint in developing more sophisticated charging/compensation schemes. Although significant strides have been made in disseminating advanced metering infrastructure on a global scale [49–51], the migration to more complex pricing mechanisms may in cases not be acceptable from a regulatory standpoint (see [52] for details on the conflicting objectives that retail tariffs are expected to serve). Thus, regulators are faced with the unprecedented challenge to make optimal trade-offs between the investment costs of advanced metering infrastructure, that would in principle allow the smooth transition to more heavily DG-penetrated power systems, whilst providing solid investment incentives by maintaining the process simple and understandable. Nevertheless, it is imperative to explore possible rate reforms that may steer the afore-mentioned process in the right direction, although these practical limitations may persist in the near future [53].

4. Proposed alternative NEM practice for Cyprus

The critical evaluation of Section 3 has thoroughly demonstrated the need for alternative methods in determining the compensation framework of NEM customers. In this section, an alternative NEM billing process is examined. The reasoning behind this alternative practice lies with the need to explore potential ways forward from the current NEM practice in Cyprus without any extra infrastructure/metering costs.

In particular, the alternative billing mechanism refers to maintaining the current energy netting process, yet charging NEM customers for their use of the system based on the energy that is drawn from the grid. To this end, the alternative billing mechanism could take into account the imported and exported energy amounts of each NEM customer and associate these with compensation figures that reflect on the individual use of the system of each particular NEM customer; at least on a volumetric basis.

Thus, the alternative NEM scheme is an energy crediting mechanism which relies on a bimonthly energy netting process. To this extent, the billing process is described below:

- Initially, a subtraction of the volume of imported energy by the respective volume of exported PV generation takes place
- In case the difference is positive, the NEM customer pays for the net energy amount through his retail tariff. The energy amount that is charged through the retail tariff is called the customer's billed consumption
- Subsequently, the NEM customer is also required to pay an extra, explicitly calculated UoS charge (including the time diversity charge) for the grid-imported energy minus the already billed consumption. In other words, each kWh that has been imported from the grid (i.e. delivered by EAC) is either implicitly (through the retail tariff) or explicitly charged the UoS charges
- Conversely, in case where the PV generation volume is larger than the imported energy, the customer pays no energy charges through the EAC05 tariff (i.e. the billed consumption is equal to zero) and the negative energy amount is transferred on to the next billing period as energy credit to offset future consumption. Nevertheless, the NEM customer is still required to pay the respective UoS charges for the amount of energy that was imported from the grid.

Fig. 10 graphically illustrates this process. Moreover, an example of the billing process is shown in Table 10 and is compared to the current NEM practice in Cyprus.

As shown in section 3.4, the total PV generation of NEM customer is either self-consumed or exported to the grid; thus, it is evident that a customer with high PV energy exports exhibits a low SCR whereas a customer with low PV energy exports exhibits a high SCR. To this extent, the NEM customer's perspective reflects on the difference between the UoS charges under the alternative NEM scheme and the UoS charges that currently apply in Cyprus. As can be seen in Table 11, the difference is an inherent function of each customer's SCR. Thus, the alternative scheme provides an effective incentive for self-consumption since the behind-the-meter consumption of self-produced PV energy avoids the full EAC retail rate and is not required to pay any UoS charges.

In order to quantify the EAC UoS revenue change, three examples of SCR distributions are shown in Fig. 11 for approximately 22,000 NEM customers in Cyprus. Each distribution results in average 30%, 50% and 70% SCR respectively. The average SCR in each case results from the weighted average of the corresponding normal distribution shown in Fig. 11. The aim here is to exemplify that NEM customers may utilize their PV generation differently. To this end, their impact on the final collectable UoS revenue compared to the current practice is illustrated in Fig. 12. Specifically, the weighted SCR average of the three hypothetical distributions is used to calculate whether EAC will experience an increase or a decrease in its final collectable UoS revenue. As can be extracted from the graph, if the average SCR of NEM customers is below 55%, then EAC will experience an increase in UoS revenue. Conversely, if the average SCR is above 55%, then EAC will experience a decrease in UoS revenue.

A limitation of this alternative NEM scheme relates to the fact that self-consumed PV generation may not directly lead into EAC costs decrease. This is because network costs are mainly driven by the peak demand, and not by the variations in the drawn amounts of electricity [54]. However, the alternative scheme is compatible with the traditional utility business model, which dictates that cost recovery occurs by charging the energy volumes that are imported from the grid. To this extent, it is clear that depending on how the actual self-consumption pattern of all NEM customers is distributed, EAC may experience different UoS revenue changes.

5. Conclusions

NEM schemes have been proven successful in attracting demand-side investment in distributed generation thus giving rise to prosumers due to their simple and understandable form. However, these schemes also constitute a major challenge for utilities and regulators due to the fact that the costs and benefits that NEM customers bring to the system have to be directly associated with the underlying retail tariffs in order to preserve the simplicity and attractiveness of the policy.

To this extent, the small, isolated and highly fossil-fueled power system of Cyprus is expected to be increasingly penetrated by prosumers due to the falling capital costs of PV systems and the high solar potential of the country that deem such investments financially viable under most circumstances. Nevertheless, the critical review performed in this paper has demonstrated that the current NEM practice in Cyprus may not prove sustainable in the long-term due to a series of financial implications that are embedded in the way that UoS costs are recovered from prosumers. Specifically, the current NEM practice in Cyprus charges prosumers based on the rated capacity of their PV systems thereby ignoring their actual interaction with the grid. This cost recovery method implies two kinds of undesirable cross-subsidies: a) from regular customers to prosumers –due to the fact that the current charges may not be representative of their actual interaction with the grid– and, b) from prosumers with high self-consumption to prosumers with low self-consumption –due to the fact that the current charges rely on the rated capacity of the prosumers' PV systems and not on how they utilize their privately-produced PV energy.

Moreover, prosumers in Cyprus seem to be compensated twice for reducing system losses. This is due to the existence of a relevant credit in the current NEM practice that is extra to the UoS charges that prosumers are required to pay. However, since the EAC05 retail tariff entails appropriately elevated energy charges (through the embedded loss factor for LV customers) in order to recover losses-related costs, then the retail rate that prosumers are allowed to avoid rewards them for this benefit they bring to the system. This extra credit assignment is a proof for the importance of accurate information exchange between utilities and regulatory authorities in order to avoid pricing distortions as much as possible.

Finally, the current NEM metering implementation (i.e. the use of a single bidirectional meter keeping records of the cumulative imported and exported energy amounts) allows the application of an alternative NEM billing process that alleviates the majority of the existing financial implications of the NEM practice in Cyprus. This is achieved by basing the UoS charges on the grid-imported energy for all customers. To this end, this paper proposed an alternative NEM implementation framework that does not discriminate between regular and NEM customers. This framework treats both types of customers in the same manner with regard to how they are charged for using the grid.

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