A sizing methodology based on Levelized Cost of Supplied and Lost Energy for off-grid rural electrification systems

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Off-grid renewable systems can play a pivotal role in the process of rural electrification, thus promoting local development. Moreover, scientific literature is increasingly addressing this issue through the concept of sustainability and appropriate technologies. With regards to this topic, we present a sizing methodology which better relates the results and the sizing process itself to the local context. Specif-ically, we address the research area of sizing methodologies for off-grid PV systems. Typically, the Loss of Load Probability (LLP) is a key parameter in these methodologies, but is difficult to set as regards the specific context. The proposed methodology employs the concept of Levelized Cost of Supplied and Lost Energy, it is based on the estimate of an economic Value of Lost Load, and eventually, the LLP results to be an output of the process. Therefore, the methodology uses only data characterizing the local situation and results better fit with population conditions. We also propose a simple approach to compute the Value of Lost Load and we apply the methodology for a rural area of Uganda. The results show that the methodology identifies a reliable system which supplies electricity with a fair cost while minimizing the energy bill of the consumers.

Keywords: Developing countries, System sizing, Off-grid Photovoltaic, Simulation, Optimization

1. Rural electrification of developing countries and off-grid systems

Rural areas of developing countries are those which suffer the poorest access to modern energy services. In fact in these contexts, the livelihood of large segments of the population is mainly determined by energy supplied via traditional biomass, kerosene and small batteries [1,2]. Moreover, the electric supply system, when available, is often unreliable (Table 1) and still nowadays it does not reach the majority of the total population. Indeed, electrification rates of rural areas are the lowest (Table 2), thus bringing about an insurmountable barrier to the improvement of households welfare, to the provision of local services, and to the development of productive activities.

When compared with the traditional approach of main-grid extension, stand-alone and micro-grid power systems (i.e. off-grid systems) are often considered the most proper solution — at least as a first step — in the process of rural electrification [3]. Indeed the International Energy Agency estimated that 55% of the additional generation required to achieve the *Energy for All Case* in 2030 is expected to be generated through off-grid solutions which are supposed to be totally employed for rural electrification [4,5]. Off-grid systems are typically based on renewable sources thus reducing dependency on fossil fuels, they are modular and hence can be adapted to different rural energy needs, and they are located near to the consumers thus avoiding transmission and distribution costs [6].

The issue of rural electrification via off-grid systems is often considered in the frame of *sustainable development* and *appropriate technologies*. Indeed, a few examples taken for the broad peer-reviewed literature show that analyses address (i) sustainability assessment as regards energy access in rural areas [9], (ii) new approaches in promoting local development through electricity access [10], (iii) technologies selection according to features of local context and population [11,12], and (iv) multi-objective system sizing which embraces technical, economic and environmental parameters [13,14]. These researches deal with different aspect of rural electrification and renewable technologies while also embracing, distinctly or not, (a) the concept of energy needs and the matching of such needs without compromising the environment, hence considering sustainable development, and (b) the concept of technologies design or selection including specific

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Nomenclature

Acronyms used in the text

LCC	Life Cycle Cost
LCoE	Levelized Cost of Energy
LCoSLE	Levelized Cost of Supplied and Lost Energy
LHV	low heating value
LL	Loss of Load
LLP	Loss of Load Probability
NOCT	Nominal Operation Cell Temperature
NPC	Net Present Cost
NPC*	new proposed Net Present Cost
PV	photovoltaic
SOC	State of Charge
VOLL	Value of Lost Load

Symbols

$(P/E)_R$	battery power-to-capacity ratio
$C_{B,mobile}$	mobile battery capacity
App Name	name of appliance
B_{size}	battery rated capacity
$c_{recharge\ mobile}$	mobile charge cost
c_{diesel}	diesel cost per liter
CF_i	cycles to failure
$c_{ker\ lamp,h}$	kerosene cost for 1h light
Class Type	*name of user class*
E	electricity supplied to consumers
E_{Bat}	energy flow through the battery
$E_{class,day}$	class daily energy need
E_D	electricity demand
$E_{pc,year}$	per capita yearly energy need
E_{PV}	energy produced by PV
$E_{user,day}$	user daily energy need
G	irradiance
h	reference irradiance
h_{funct}	functioning hours
$h_{light,LL}$	hours of light relating to LL
h_{start}	functioning windows start
h_{stop}	functioning window stop
H_β	solar irradiation on a tilted surface
Inv	investment costs
$Life_{Bat}$	*battery life time in year*
LT	lifetime
m	number of depth of discharge intervals
N_{App}	number of appliance
N_{US}	number of user within a class
O&M	operation and maintenance costs
P_{App}	appliance power rate
$P_{el,light}$	average power of electric lights
$P_{eq,App}$	equivalent appliance power
PV_{size}	PV power rate
r	discount rate
t	simulation time-step
T	time period
T_{Amb}	ambient temperature
T_{Cell}	PV cell temperature
Tot_W	total functioning windows hours
v	diesel specific volume
$V_{B,mobile}$	mobile battery voltage
$W_{f,n}$	functioning windows
y	year
Z_i	charge/discharge cycle
ΔE	energy balance to the battery
η_{BOS}	balance of system efficiency
η_{CH}	battery charge efficiency
η_{DISCH}	battery discharge efficiency
η_{gen}	diesel generator efficiency
η_{Inv}	inverter efficiency
ρ_T	temperature coefficient

Table 1
Electric outages and duration in developing world macro-regions.

	Number of outages (days per month)	Duration of the outages (hours)
Sub-Saharan Africa	8.0	5.0
Middle East & Northern Africa	25.8	12.4
East Asia & Pacific	3.3	2.0
Latin America	2.5	1.3
South Asia	18.0	1.3
World	5.3	2.7

Source [7].

conditions of the targeted areas (people's needs, and social, cultural aspects), hence considering the concept of appropriate technologies [15].

Coping with these concepts, a sizing methodology for off-grid systems which better relates the results as well as the sizing process itself to the specific features of the local context is suggested in this paper. Specifically, we address the area of interest of sizing methodologies for off-grid PV systems. The proposed methodology employs the concept of Levelized Cost of Supplied and Lost Energy (LCoSLE), it does not require the Loss of Load Probability (LLP) as input datum, and it is based on the estimate of the economic Value of Lost Load (VOLL) for the targeted context. The methodology uses as input only data that characterize and come from the local situation, and hence, in our opinion, it is more appropriate in designing energy systems for rural electrification.

The paper is structured as follows: in Section 2 we briefly review the methodologies for off-grid PV system sizing and we highlight the limitations as regards the application in rural areas of developing countries, in Section 3 we present the new methodology while in Section 4 we propose a procedure to define the VOLL for a rural context. Finally, we explain the overall structure of the novel sizing methodology (Section 5) and we apply it to a case study for a PV micro-grid in a rural area of Uganda (Section 6). The physical model of the micro-grid as well as the numerical technique employed to optimize the system size are quite similar to others available in the literature and we briefly describe them in Appendix A. All numerical examples as well as graphs that we show in the paper refer to the mentioned physical model, the numerical technique and to the Ugandan case. Finally in Appendix B a detail of the figures adopted for the study is reported.

2. Sizing techniques for off-grid PV systems

In the context of renewable technologies, off-grid PV systems are those which probably will contribute the most to rural

Table 2
Regional aggregates for electricity access (2011).

	Population without electricity [millions]	Electrification rate [%]	Urban electrification [%]	Rural electrification [%]
Africa	600	43	65	28
Developing Asia	615	83	95	75
Latin America	24	95	99	81
Middle East	19	91	99	76
Developing countries	1257	76,5	90.6	65.1
Transition economies & OECD	1	99.9	100.0	99.7
World	1258	81.9	93.7	69.0

Source [8].

electrification in the near future. Indeed, solar energy is the most available renewable energy source in developing countries [16] and it is expected to contribute to about 36% of the additional generation of the *Energy for All Case*. PV systems are also becoming more and more popular in rural areas thanks to a growing market that benefits from an appreciable decreasing of components costs, from the integration of PV technology in rural electrification programs, and from an increasing commitment of Multinational Corporations due to the huge potential market [17–20].

Sizing off-grid PV systems is not straightforward since it means matching an unpredictable energy source with an uncertain load demand while providing the most favorable conditions in terms of system reliability and cost. Sizing techniques are based on the solving of the balance between solar radiation and load demand, taking into consideration the features of the system components. Differences mainly result from the length of the *time-step* the balance is solved for, and from the methods employed to look for an optimal solution: a short time-step and a great complexity of the solver are accompanied by a high degree of detail in the solar and load data and in the mathematical modeling of the system components.

Khatib et al. in Ref. [21] have recently reviewed these sizing techniques: they have classified them into three categories (intuitive, numerical and analytical), and they have focused the analysis also on rural electrification. According to this review we can infer that, except for the simple intuitive sizing methods, whatever techniques are employed, they ultimately search for an optimal combination of system reliability and cost. In fact, system reliability is proportional to system cost, and hence the greater the reliability the higher will be the cost and vice versa. Therefore, any technique aims at optimizing the system by analyzing the relationship between reliability and cost in order to find the best trade-off [22].

System reliability can be identified with the *Loss of Load Probability*, which is the share of the electricity demand (E_D) not fulfilled by the power system over a certain period (T) [23,24]:

$$LLP = \frac{\sum_{t=1}^{T} LL(t)}{E_{D,T}} \quad (1)$$

where $LL(t)$ is the *Loss of Load* (i.e. the demand load not fulfilled) at the time-step (t).

The system cost is commonly identified by means of the *Net Present Cost* (NPC), which is defined as the present value of the sum of discounted costs that a system incurs over its lifetime (LT) [25]:

$$NPC = \sum_{y=1}^{LT} \frac{Inv(y) + O\&M(y)}{(1+r)^y} \quad [€] \quad (2)$$

where, for each year (y): $Inv(y)$ considers the investment and replacement costs of the system components, $O\&M(y)$ are the operation and maintenance costs, and $(1+r)^y$ is the discount factor.

A further consideration resulting from the review is that, except for the intuitive methods, whatever techniques are employed, as input datum they all require a target level of reliability, i.e. a maximum value of LLP that is tolerated by the consumers. Then, the optimization process generally consists in searching for the combination of the system components sizes (i.e. PV array size and battery bank size), which have the minimum NPC while fulfilling the LLP condition [24].

In our opinion this optimization approach has an important defect, particularly when applied to system sizing for electrification project in rural areas of developing countries. Indeed, for the conditions that occur in these contexts, neither system designers nor customers have any specific reference which can lead to set a context-appropriate LLP target value. In fact, for off-grid applications in developed countries, the reliability of the existing electric supply service can be a benchmark for designers and, in any case, also customers have sufficient experience with the electric service to understand and contribute to defining the targeted LLP since they are aware of the relation with costs. On the contrary, in rural areas of developing countries neither designers nor customers have any frame of reference about reliability, indeed: (i) it is unreasonable to consider the national centralized grid due to the frequent outages (Table 1), (ii) rural people not reached by the grid do not have any experience with a supply service, and (iii) even people who have access to electricity (e.g. typically in the case of small autonomous diesel generators and rechargeable batteries), decide to consume it according to the importance of the need, the cost, and the energy source availability, i.e. the Loss of Load concept is meaningless in this case. Actually, the definition of correct reliability levels within the scientific literature is still an open issue [26]. Indeed, while Wenham et al. [27] generally suggest that the type of loads should determine the system reliability; on the contrary, in a number of papers no procedures or considerations about the features of the users' conditions are employed in setting the target LLP (e.g. Refs. [22,24,28–32]). System reliability mostly results in the range of 0.95–1 and it appears as a *researchers' recommendation*. Therefore, we think that this optimization process, but also the sizing outputs may result inappropriate to rural areas of developing countries.

3. A sizing methodology designed for rural areas of developing countries

In developing the sizing methodology our main aim was to have a design process and the relating results which are appropriate as regards the context of rural areas of developing countries. We address this objective by considering two elements:

1. both the process and the results have to be linked to the features of the local context, and hence the parameters and assumptions which drive the system optimization cannot be defined externally. Specifically this means that the LLP of the plant has to be

considered with a different approach compared with the *traditional techniques*. Nevertheless, systems which are more reliable must be favored over those which are less reliable, hence the sizing process cannot prescind from embracing the Loss of Load parameter;
2. the electricity cost should be as low as possible. Indeed from the final users' perspective and particularly in poor rural contexts, services must be as affordable as possible.

In order to meet the first point we propose to introduce in the computation of the NPC a further cash flow which accounts for an economic value of the energy not supplied. The idea is that a new off-grid PV system will provide a power supply service which will substitute the energy devices/systems already in place and in use by local users (e.g. kerosene lamps, batteries, small diesel generators, etc.; we refer to these as *traditional systems*). Nevertheless, when the new system incurs in a Loss of Load, it can be assumed that the consumers might go back to the traditional systems in order to fulfil the assumed energy needs. This results in them going to further energy expenses that we express by means of the VOLL, which is the economic Value of Lost Load in the targeted context [€/kWh_{LL}].

The modified NPC is defined as follows:

$$NPC^* = \sum_{y=1}^{LT} \frac{Inv(y) + O\&M(y) + \sum_{t=1}^{T} LL(t)*VOLL}{(1+r)^y} \quad [€] \tag{3}$$

This definition contributes to favor the most reliable systems because we *internalize* into the NPC a cost associated with the Loss of Load which contributes with higher values for less reliable and cheaper systems, and with smaller values for more reliable and more expensive systems. With this approach the problem relating to the definition of the LLP is shifted to the necessity to estimate the VOLL.

In order to meet the second point we propose to employ a modified definition of the *Levelized Cost of Energy* (LCoE) as the objective function of the proposed methodology. The LCoE is defined as the price for electricity that would equalize the present value of the sum of discounted costs (i.e. the NPC) and the present value of the sum of discounted revenues as follows:

$$\sum_{y=1}^{LT} \frac{E(y)*LCoE}{(1+r)^y} = \sum_{y=1}^{LT} \frac{Inv(y) + O\&M(y)}{(1+r)^y} = NPC \tag{4}$$

where *E(y)* is the electricity served each year to the consumers by the system.

The LCoE is a convenient tool for comparing the unit costs of different technologies over their economic life, and it is closer to the investment costs for electricity production in monopoly markets with regulated prices rather than to the investment costs in competitive markets with variable prices [33]. Monopoly markets are the common situation in developing countries where, in addition, incentive schemes for off-grid renewables are seldom implemented [34]. Therefore the LCoE can be considered a reference value for the electricity cost that rural consumers would face. Moreover, it has also been employed as objective function in a number of analyses that deal with renewable-based off-grid systems (e.g. Refs. [14,35,36]).

We modified the traditional definition of the LCoE by considering the internalization of the VOLL-related costs. Therefore, the new definition refers to the NPC* and we named it *Levelized Cost of Supplied and Lost Energy* (LCoSLE):

$$\sum_{y=1}^{LT} \frac{E(y)*LCoSLE}{(1+r)^y} = \sum_{y=1}^{LT} \frac{Inv(y) + O\&M(y) + \sum_{t=1}^{T} LL(t)*VOLL}{(1+r)^y} = NPC^* \tag{5}$$

Given the loads demand, the solar source availability, the techno-economic features of system components, and the VOLL, the LCoSLE function (Eq. (6)) identifies a single combination of PV array and battery bank size which supplies electricity at the cheapest cost (Fig. 1). Moreover, an NPC* value and an LLP value are output parameters of the optimum plant.

$$LCoSLE^* = f(PV_{size}, B_{size}) = \frac{r*(1+r)^{LT}}{(1+r)^{LT} - 1} * \frac{NPC^*}{E(y)} \quad [€/kWh] \tag{6}$$

A number of considerations show, in our opinion, that the LCoSLE is an appropriate parameter in sizing off-grid PV systems for rural electrification. In fact, (i) it is based on the estimate of the VOLL which can be related to the local context features, (ii) it does not require an LLP input datum, (iii) it identifies the optimum system univocally once the VOLL is set, and (iv) it identifies an optimum system which is tailored to the local conditions. Indeed, if the VOLL increases, the optimization process looks for a trade-off between investment costs and Loss of Load-related costs (i.e. *traditional energy expenses*), and it returns a system with larger components sizes, higher NPC, but lower LLP thus limiting the traditional energy expenses (Fig. 2). The opposite occurs when VOLL decreases.

Additional considerations can be made by comparing the proposed sizing methodology and the traditional one in order to further stress the features that make the proposed methodology appropriate and to show the differences in the results. The comparison is carried out with reference to Fig. 3, which shows the relation between Life Cycle Cost (LCC) and LLP for optimum off-grid PV systems when the novel and the traditional sizing processes are employed. Specifically:

- the *x-axis* reports the Life Cycle Cost of the systems, i.e. the NPC* in case of the new methodology and the NPC in case of the traditional one; the *y-axis* reports the LLP;
- the solid line shows the trend in the LLP and the LCC that are associated to optimum systems using the proposed methodology and once the VOLL is set;
- the dotted line shows the trend in the LLP and the LCC that are associated with optimum systems using the traditional approach and once the LLP is set.

At least three statements can be made:

1. the LLP is an output of the system optimization and its value is related to the context. Indeed, given a VOLL, there is an optimum LLP which refers to certain PV and battery sizes, and which brings about an amount of PV system cost and traditional energy expenses thus leading to the minimum cost of energy. This is the optimum and most appropriate system for that context;
2. comparing the results for the same LLP value (e.g. *LLP 1*) the LCC is *Cost 1* for the traditional approach, and *Cost 2* for the new one. The difference between the two values (*A*) refers to Loss of Load-related costs that are not considered in the traditional approach. Indeed, the new methodology embraces all the expenses relating to the consumers' needs: the PV system cost (*Cost 1*) and the traditional energy expenses (*A*);

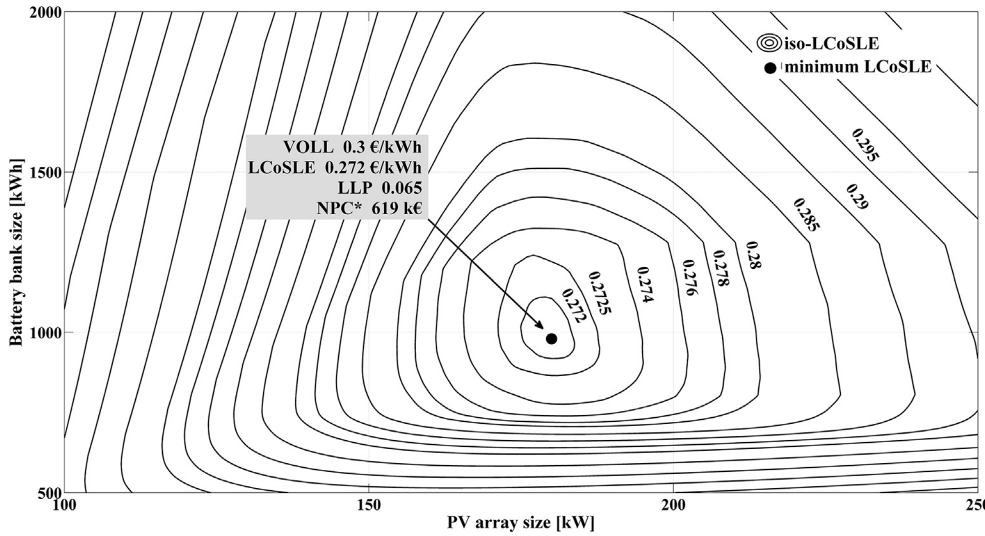

Fig. 1. LCoSLE function trend and minimum.

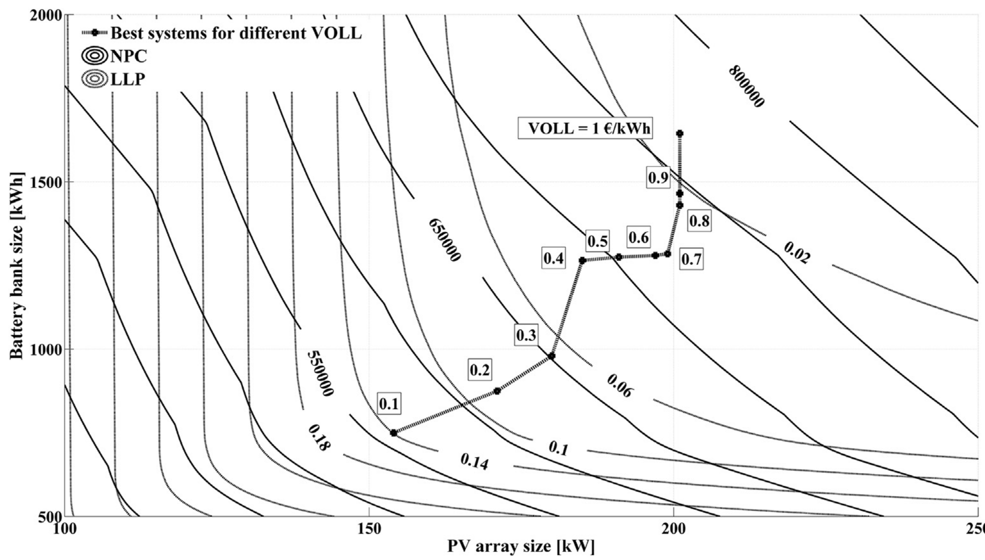

Fig. 2. Best systems combinations for different values of VOLL.

3. comparing the results for the same LCC value (e.g. *Cost 2*) — that is: the consumers have a limited budget assigned for the electric energy needs — the traditional approach suggests a system with *LLP 2*, which has larger components and smaller LLP than the system suggested by the new one (*LLP 1* in case of VOLL 0.28 €/kWh$_{LL}$). As a consequence, while with the new approach the designer has complied with the consumer limit since the budget will cover both PV system cost and traditional energy expenses, with the traditional one the budget will be overrun since further expenses will occur due to the Lost Load (*B*). In this case the LCC will finally be *Cost 3*: about 725 k€ with VOLL 0.28 €/kWh$_{LL}$.

As a final remark we can state that the main peculiarity of the proposed sizing methodology is the capability, given an economic value of the electric energy unit at local level, to optimize the off-grid PV system in order to minimize to overall expenditure that targeted consumers face in meeting the electric energy needs. This comprises the cost associated with the PV system, but also those associated with compensating the Loss of Load with traditional energy systems.

4. An approach to estimate the Value of Lost Load

The key parameter of the proposed sizing methodology is the Value of Lost Load (VOLL) which we have stated can be computed as regard the specific features of the targeted context. In the scientific literature, a field of research deals with the VOLL which is considered as a monetary expression for the costs associated with interruptions of electricity supply (e.g. Refs. [37,38]). Van der Welle and Van der Zwann [39] define VOLL as the total economic damage caused by undelivered electric energy divided by the amount of undelivered electric energy. From their review some considerations can be made about the VOLL concept:

- it has arisen in the context of developed countries, hence where electric systems are fully developed;
- it has arisen from analyses about security of the supply in economies which deeply rely on electric energy, hence where electricity is supposed to be always available;
- it is linked to the concept of the local electric market and is determined by its characteristics;

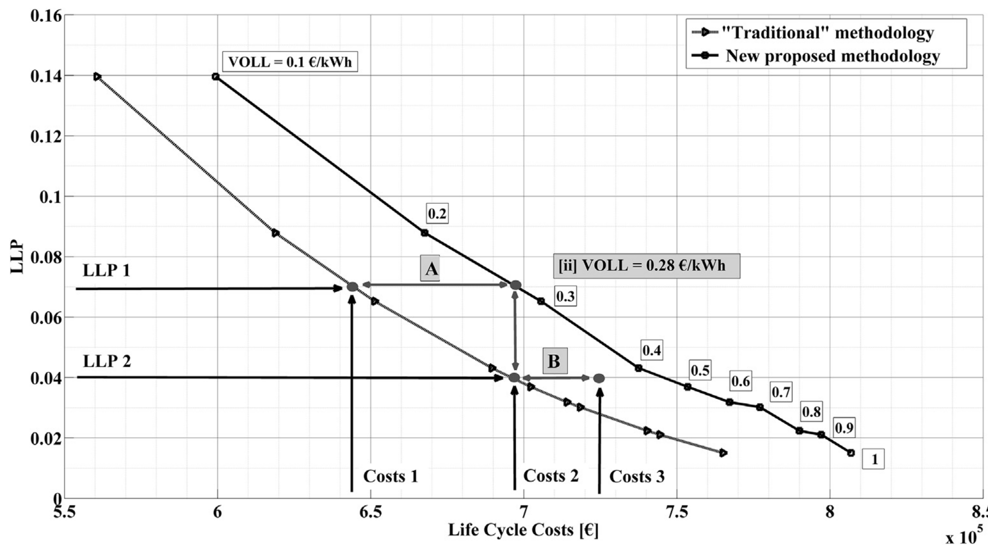

Fig. 3. Comparison between the proposed sizing methodology and the traditional one.

- the estimated value is determined by the causes, the features, and the consequences of supply interruptions;
- there are a number of methodologies to compute the VOLL (e.g. revealed preferences, stated preferences, proxy methods, case studies).

Based on this overview, we can state that the concept of an economic value associated with the Loss of Load has been already employed, there are several methodologies, and it undoubtedly depends on the features of the reference context. Nevertheless, in our opinion, the methodologies available in the literature are heavily oriented towards electrical systems of developed countries or, in any case, to centralized systems and they can hardly be used for our targeted context. Therefore, in this paper, we propose a simple procedure (which can be further developed), which may fall within proxy methods, and which estimates the VOLL on the basis of two assumptions:

1. when losses of load occur the consumers fall back on traditional energy systems to meet the expected energy needs;
2. the VOLL relates to the cost associated with the use of traditional energy systems.

These assumptions presume that in the targeted context there is no electric supply service, thus the concept of interruption does not apply, and all the consumers still have a back-up system (i.e. the traditional energy systems). Therefore, as a first approximation, there is no economic damage due to losses of load, except for the traditional fuel costs.

The proposed procedure consists of five steps:

1. to compute the daily electricity consumption associated with each device available within each consumer class, and the daily electricity consumption of each class (section 5.2);
2. to identify the traditional energy systems which substitute the electric devices. We consider two classes of rural consumers: those who already have electricity via small diesel generators, and those rely on kerosene for lighting purposes and on recharge services for mobile phones batteries;
3. for each traditional energy system it is necessary to estimate the VOLL. We consider (i) diesel generators, (ii) kerosene lamps and (iii) recharging mobile service.

For case (i) VOLL relates to diesel costs as follows:

$$VOLL_{diesel} = \frac{c_{diesel}}{\eta_{gen} * LHV * v} \qquad [€/kWh_{LL}] \tag{7}$$

where c_{diesel} [€/lit] is the local cost of diesel, η_{gen} is the efficiency of the generator, LHV [kWh/kg] is diesel low heating value, and v is diesel specific volume [kg/lit].

For case (ii) VOLL is computed considering the equivalence between electricity and traditional systems in terms of time the light is needed. Assuming a reference rate power of electric lights ($P_{el,light}$), which can be the actual power rate of the available light (if only one is available) or an average power (if multiple lights are available), the associated hours of light related with 1 kWh_{LL} can be computed:

$$h_{light,\,LL} = \frac{1}{P_{el\ light}} \qquad [h/kWh_{LL}] \tag{8}$$

then VOLL results:

$$VOLL_{\ker\ lamp} = c_{\ker\ lamp,\,h} {}^* h_{light,LL} \qquad [€/kWh_{LL}] \tag{9}$$

where $c_{ker\ lamp,h}$ [€/h] is the cost relating to the consumed kerosene during one hour of lamp functioning and can be computed by means of average data among households.

For case (iii), the traditional solution is to charge mobile phones at kiosks or market places that provide charging services. Considering the battery capacity ($C_{B,mobile}$), the charging voltage ($V_{B,mobile}$), and the price for the charging service ($c_{recharge,mobile}$), VOLL is:

$$VOLL_{mobile} = \frac{c_{recharge\ mobile}}{C_{B,mobile} * V_{B,mobile}} \qquad [€/kWh_{LL}] \tag{10}$$

4. for those consumer classes who employ different traditional energy systems it is necessary to compute a *class-VOLL*;
5. finally, the *overall-VOLL* is calculated by summing up weighted class-VOLL values.

5. Overall structure of the proposed methodology

Both the computation of the VOLL and the LCoSLE are elements of a sizing process that include several steps. Indeed, we show in Fig. 4 the overall structure of the proposed sizing methodology. This structure refers to the complete process that we implement in MATLAB® in order to apply the novel sizing methodology to a real case study (Section 6). It includes: (i) three *building blocks* which process the main input data, (ii) the *optimization process*, (iii) a further set of *sizing settings*, and (iv) the *sizing results*.

The building blocks elaborate the *primary input* data in order to obtain a set of proper *outputs* for the optimization process. The optimization process implements a *physical model* of the system which comprises three components (PV array, battery bank, and inverter) and it accomplishes the optimization by means of a numerical technique. This technique performs lifecycle *simulations* of all the combinations of PV array and battery bank within user-defined size ranges and it computes the LCoSLE. Then the components combination which results to have the minimum LCoSLE is *detected* as the optimum system. Furthermore, system components techno-economic *settings* as well as optimization settings are required by the optimization process.

In the previous sections we describe the VOLL building block as well as the LCoSLE-based objective function, while in the following we detail the *Solar Resource* and the *Load Demand* building blocks. On the other hand, both the physical model of the system as well as the numerical technique are quite similar to others available in the literature, and hence we report the main implemented features in Section 5.3 while we provide a description of the core equations in Appendix A.

5.1. Solar resource data

Usually in rural remote areas of developing countries no weather stations are available, therefore a general approach to obtain solar resource data for these contexts consists in three steps: (i) *mean daily solar irradiations* and *ambient temperatures* can be obtained from the Surface meteorology and Solar Energy website of the NASA [40], (ii) the *synthetic hourly solar radiation incident* on the surface of the PV array can be computed by means of the method available in Refs. [41,42], (iii) the *PV cell temperature* can be calculated by means of the procedure shown in Ref. [43]. Time series of radiation and cell temperature are employed to compute the power production profile of the PV array throughout the year.

5.2. Demand load data

A single daily demand load curve, as representative of each day of the year, is required for the system simulations and is adequate to perform the optimization. Specifically we employed a bottom-up procedure to build up the load curve:

1. we identified a number of user classes (*Class Type*) and we defined the number of users within each class (N_{US});
2. we defined type (*App Name*), rate power (P_{App}), and number (N_{App}) of electrical appliances available for each user of each class;
3. for each electrical appliance, we assumed the functioning hours (h_{funct}) and the possible functioning windows ($W_{f,n}$), i.e. the space of hours when an appliance can work:

$$Tot_w = \sum_{n=1}^{Num\ Win} W_{f,n} \quad [h] \tag{11}$$

$$h_{funct} \leq Tot_w \quad [h] \tag{12}$$

In Table 3 we show an example of the estimated load data for a user class.

4. the contribution of each appliance to the load curve is given by the equivalent constant power ($P_{eq,App}$) throughout the functioning windows which would equalize the required energy:

$$P_{eq,\ App} * Tot_W = P_{App} * h_{funct} * N_{App} \quad [kWh] \tag{13}$$

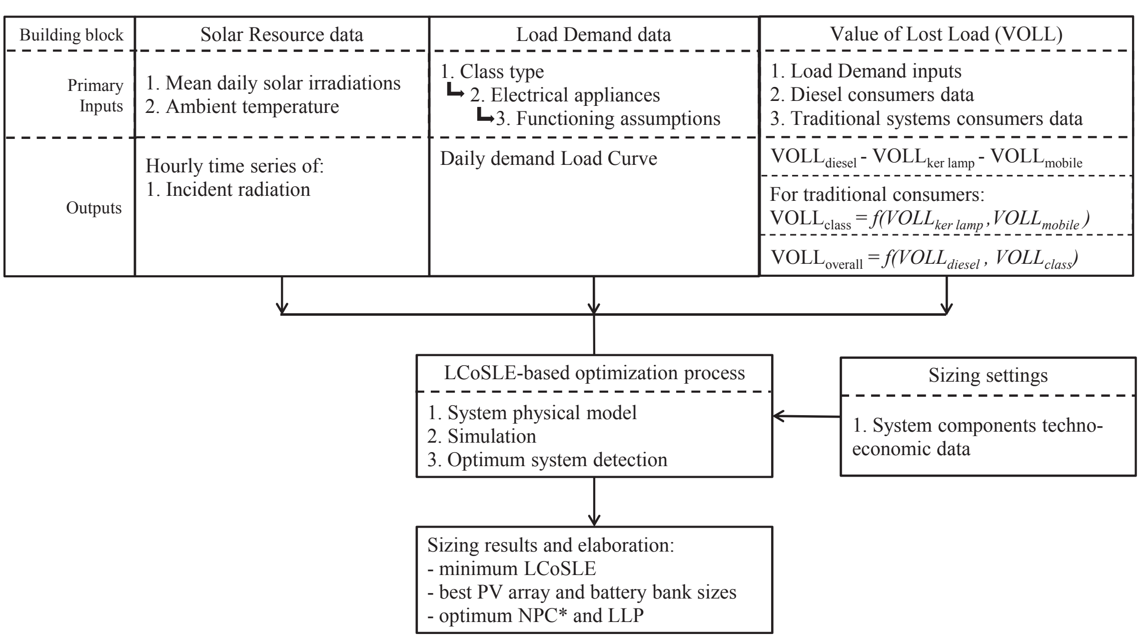

Fig. 4. Overall structure of the novel sizing methodology.

Table 3
Example of assumed load demand data for a user class.

Class type	N_{US}	App name	P_{App} [W]	N_{App}	h_{funct}	$W_{f,1}$		$W_{f,2}$		$W_{f,3}$		Tot_W
						h_{start}	h_{stop}					
Family_1	50	Lights	3	4	6	0	2	17	24	–	–	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Security Lights	5	1	12	0	7	17	24	–	–	14

5 the daily demand load curve was finally computed by adding together the contribution of each and every appliance considering the number of users within each class.

5.3. Main features of the system physical model

Main features of the mathematical modeling of the implemented components and simulation approach can be summarized as follows:

- the effect of the cell's temperature on PV array power output was applied;
- a minimum State of Charge of the battery bank (SOC_{min}) was considered;
- a battery bank power-to-energy ratio $(P/E)_R$ was considered in order to introduce a constraint to the maximum power output of the battery bank as regards the rated capacity;
- the lifetime of the battery bank was considered by using the *rainflow* cycle counting method [44,45];
- the inverter size was defined as regards the power peak occurring within the load curve and considering the inverter efficiency;
- simulations are based on hourly time-steps.

6. Sizing PV micro-grid main components for a rural area in Uganda

Hereafter we describe the application of the proposed methodology for the sizing of the main components of a PV micro-grid located in a rural area of Uganda. All the assumptions and input data are the results of activities carried out during a two-months mission in Uganda.

The specific location of the micro-grid is Soroti, which is a small town in the central-east of Uganda (1.72N/33.6E). In Soroti the electric grid reaches only few business activities and houses in the city center, while part of the population use small diesel generators to power domestic appliances and working equipment. Moreover, there are large residential areas where households live without electricity and make use of traditional systems to satisfy their basic needs. We surveyed the typical conditions of the peripheral areas of Soroti and we considered a hypothetical micro-grid which addresses the energy needs of 100 households and usual relating activities (e.g. micro and small enterprises, kiosks, market place, school, etc.).

6.1. Solar resource and load demand data

Primary inputs of *Solar Resource* are reported in Table 4 and they show that solar energy potential of the region is interesting for PV applications due to high values of irradiation.

As regards primary inputs of *Load Demand*, we assumed that in the area reached by the micro-grid dwell 100 households which can be divided into six user classes according to the income levels. Moreover, we consider also 11 user classes which comprise business activities and local services. In the baseline situation, the households falling within class *Family_1* have the lowest income and rely on traditional energy systems for their energy needs (Table 3), on the contrary all the other household-related classes as well as the business activities and services have small-scale diesel generators. In Table 5 we report a summary of the user class energy consumptions resulting from the context-based assumptions and considering 8 persons per households [46]. The details of each user class are listed in Appendix B. The resulting demand load curve is shown in Fig. 5.

6.2. Computation of the Value of Lost Load

As mentioned before, in the rural context under consideration a number of households and activities use small diesel generators. However, there are residential areas where families live without electricity and they rely on traditional solutions to satisfy their basic energy needs. In these circumstances, the calculation of the VOLL needs to take into account the dichotomy between users who did not have electricity before the installation of the PV micro-grid and those who had electricity via diesel generators.

Following Eqs. (7) (9) (10) and on the basis of context based techno-economic information (Table 6), we computed the VOLL values for the traditional energy systems considered (Table 7).

To calculate the VOLL for user class *Family_1* the relative weights of the two traditional systems need to be considered. Considering that lighting load is 70% of the total needs and mobile-phone charging the remaining 30%, the final VOLL results:

$$\begin{aligned} VOLL_{Family\_1} &= VOLL_{\text{kerlamp}}*0.7 + VOLL_{mobile}*0.3 \\ &= 7.92 \quad [€/kWh_{LL}] \end{aligned} \tag{14}$$

Finally, to calculate the overall VOLL the relative weights of the two main user classes (i.e. those who have diesel generators and those who do not) need to be considered. Table 5 shows that diesel-based users account for 98.8% of the total day load, while traditional users account for the remaining 1.2%:

Table 4
Solar resource and temperature data for Soroti.

Month	Mean daily irradiation [kWh/m^2/day]	Ambient temperature [°C]
January	6.22	21.9
February	6.56	22.5
March	6.36	21.9
April	5.99	21.1
May	5.72	20.7
June	5.39	20.7
July	5.29	20.8
August	5.67	21.1
September	6.22	20.8
October	6.01	20.5
November	5.83	20.6
December	6.07	21.2

Table 5
Summary of energy consumptions for the defined user classes.

	Class type	N_{US}	$E_{class,day}$ [kWh/day]	$E_{user,day}$ [kWh/day]	$E_{pc,year}$ [kWh/year/pc]
1	Family_1	50	8.1	0.16	7.4
2	Family_2	15	10.2	0.68	31.1
3	Family_3	15	31.0	2.07	94.2
4	Family_4	10	31.4	3.14	143.3
5	Family_5	5	30.7	6.14	280.0
6	Family_6	5	41.4	8.28	377.9
7	Enterprise_1	15	98.7	6.58	–
8	Enterprise_2	5	130.8	26.16	–
9	Mobile Money	5	2.0	0.40	–
10	Kiosk	10	67.6	6.76	–
11	Barber	2	4.6	2.30	–
12	Tailor	3	2.6	0.87	–
13	Market Place	1	25.5	25.50	–
14	Club	3	91.1	30.37	–
15	Street Lights	1	69.0	69.0	–
16	Primary School	1	1.8	1.80	–
17	Pharmacy	1	16.9	16.90	–
	Total Load	663.4			

$$VOLL_{overall} = VOLL_{Family\_1}{*}0.012 + VOLL_{diesel}{*}0.988 = 0.33 \quad [€/kWh_{LL}] \tag{15}$$

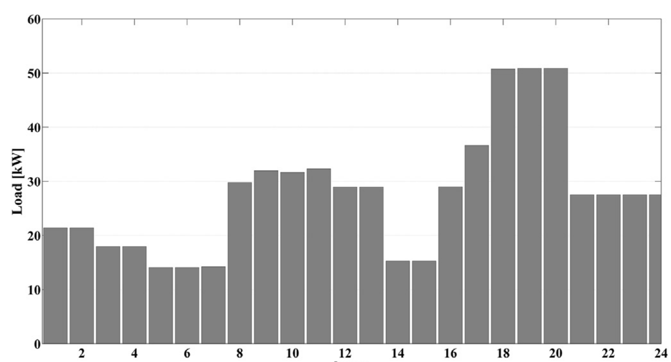

Fig. 5. Daily load curve for the targeted area.

6.3. Sizing settings

Technical parameters of the components are reported in Table 8. Component costs input data and the parameters for the economic analysis are shown in Table 9. Information about PV modules and batteries are the result of a survey among Ugandan local suppliers, while we estimated, on the basis of our experience, inverter cost as well as O&M and other investment costs. Simulations were performed ranging PV array size from 150 to 300 kW with 1 kW step and battery bank size from 500 kWh to 1500 kWh with 5 kWh step.

Table 7
Resulting VOLL values [€/kWh$_{LL}$].

$VOLL_{diesel}$	0.24
$VOLL_{ker\ lamp}$	3.97
$VOLL_{mobile}$	17.14
$VOLL_{Family\_1}$	7.92
$\boldsymbol{VOLL_{overall}}$	**0.33**

Table 8
Physical model assumptions.

Balance of system efficiency	η_{BOS}	85	%
Minimum battery State of Charge	SOC_{min}	40	%
Battery power-to-energy ratio	$(P/E)_R$	50	%
Battery charge efficiency	η_{CH}	85	%
Battery discharge efficiency	η_{DISCH}	90	%
Inverter efficiency	η_{Inv}	90	%

6.4. Sizing results

For the targeted context and following the proposed sizing methodology, the optimum plant has LCoSLE equal to 0.382 €/kWh with a PV array of 214 kW and a battery bank of 790 kWh. This system will cost 1 M€ over the lifecycle (NPC*) and will guarantee an LLP of 5.8% (Table 10).

The cost of energy results higher than the actual one for those consumers who already have power supply via small diesel generator ($VOLL_{diesel} = 0.24$ €/kWh, thus +0.14 €/kWh), nevertheless it is much lower than the actual cost for the poorest share of the population (user class *Family_1* which is half of the total) who rely on traditional energy systems and who gain access to the electric supply service ($VOLL_{Family\_1} = 7.92$ €/kWh, thus −7.54 €/kWh). As expected, the LCoSLE is also higher than the cost of the electricity provided by the Ugandan distribution company (UMEME) via the centralized system which is about 0.19 €/kWh for domestic consumers and about 0.14 €/kWh for commercial consumers [47]. On the other hand it is in line with cost assessments for off-grid systems [48].

We wish to emphasize that the proposed sizing methodology, which is founded only on data characterizing the local situation, leads to an appropriate off-grid PV system design. Indeed the results show that by means of the simple approach for the VOLL computation, the new methodology identifies a system design which is reliable and supplies electricity with a fair cost while minimizing the energy bill of the consumers.

The economic analysis is obviously affected by a number of simplifications in the micro-grid model as well as in the assumptions about the actual energy situation: e.g. the electric and control system configurations of the micro-grid, and the investment and O&M cost for small scale diesel generators were not considered. In order to cope with this uncertainty, a final sensitivity analysis may

Table 6
Techno-economic data for VOLL computation.

Diesel generator efficiency	η_{gen}	35	%
Diesel LHV	LHV	12.33	kWh/kg
Diesel specific volume	V	0.825	kg/l
Diesel cost	c_{diesel}	3000	UGX/l
Mobile battery capacity	$C_{B,mobile}$	1000	mAh
Mobile battery voltage	$V_{B,mobile}$	5	V
Recharging phone cost	$c_{recharge\ mobile}$	300	UGX/charge
Household lighting expenditure in kerosene		30,000	UGX/month
UGX-€ Exchange		3500	UGX/€

Table 9
Cost and economic parameters assumptions.

	Note	Cost	
PV modules	Monocrystalline	1000	€/kW
Battery	Lead-Acid (sealed)	140	€/kWh
Inverter		500	€/kW
Other investment costs	% on main component costs	20	%
O&M		50	€/kW/year
Plant Life Cycle	*LT*	20	Years
Discount rate	*r*	6	%

Table 10
Sizing results micro-grid Soroti.

PV array size	214	kW
Battery bank size	790	kWh
Inverter size	57	kW
Minimum LCoSLE	0.382	€/kWh
NPC modified	1000	k€
NPC	947	k€
LLP	5.8	%

bring to a better sizing process. Moreover, the optimization process identifies the single optimum combination of PV array and battery bank, these component sizes would hardly be those adopted. Indeed components availability, electric system configuration, consumer geographical distribution, etc. can affect the final requirements of PV array and battery bank sizes. In this case, it can be useful to understand the effects of non-excessive variations in the components sizes on the system performance parameters. Therefore, for the Soroti case, we show in Fig. 6 the optimum plant and the area which comprises all the components combinations with LCoSLE at the most 1% bigger than the optimum LCoSLE. We also show the optimum plants as regards different VOLL values (i.e. 0.15 and 0.60 €/kWh$_{LL}$) in order to highlight the effect of the VOLL on the optimization process. It results that system combinations which fall within 1% of the LCoSLE range from 0.04 to 0.1 LLP and from 1 M€ to 900 k€ NPC, while the same range contains the optimum systems with VOLL between 0.15 and 0.6 €/kWh.

7. Conclusion

In this paper a sizing methodology for off-grid PV systems is suggested. The methodology addresses the application of PV systems for rural electrification in developing countries and in our opinion it is more appropriate than the traditional approaches. Indeed, while traditional approaches as input datum require a target level of reliability of the system (i.e. the LLP) which is difficult to set within the framework of rural electrification, the proposed one employs the VOLL which is an economic value of electric energy not provided to the consumers and which can be related to the context features. Therefore our methodology is based only on data coming from and characterizing the local situation and hence also the results are more appropriate to the targeted context. Specifically, the new methodology is based on (i) a modification in the definition of the Net Present Cost by considering a further cost cash flow which accounts for the VOLL, and (ii) the use of the LCoSLE (based on the new NPC*) as objective function for the optimization. We also present the application of the methodology for the main components sizing of a PV micro-grid in a rural area of Uganda.

Furthermore, besides the application for PV systems, the methodology can be extended to any other renewable-based off-grid system for application in developing countries since it is an alternative approach when an LLP value is required. Finally, it is our opinion that the methodology is an example of studying the concept of *appropriateness* within the framework of research in access to energy for sustainable development. In our case, we try to address appropriateness by modifying the sizing methodologies in order to better relate the results as well as the sizing process itself to the specific features of the local context.

Appendix A. Mathematical models and numerical optimization adopted

Numerical methods for off-grid PV system sizing are quite common in the literature (e.g. Refs. [22,24,28,29,31,45,49–54]). These methods are based on system simulation, i.e. different combinations of PV array and batteries are simulated on a yearly basis and one or more criteria are used to choose the best combination that addresses the load. A simulation consists in solving the energy balance of the system and of the change in the battery state of charge (SOC) for each time-step considered, usually an hour. During and/or at the end of the simulation the decision variables are also computed, and once all the possible system combinations have been simulated, these variables lead to identifying the optimum system.

Numerical methods are preferred when accurate results are

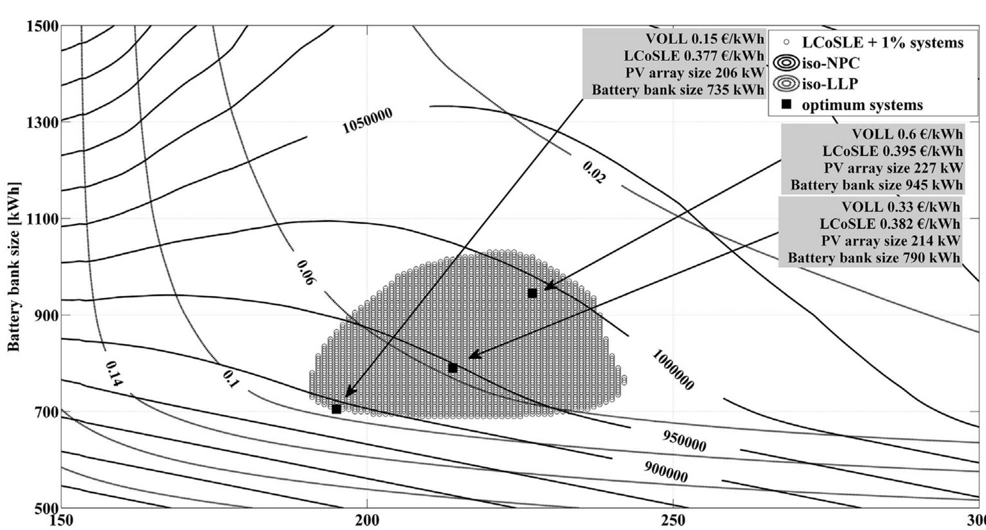

Fig. 6. Area comprising the systems with LCoSLE at the most 1% bigger than optimum LCoSLE for VOLL 0.33 €/kWh, and optimum systems for VOLL o.15 and 0.6 €/kWh.

required in order to optimize the energy and economic cost of the system. Moreover, different degree of complexity in the mathematical modeling of the system components can be easily adapted according to the type of analyses to be carried out. Drawbacks of this technique are the long calculation time required and the need of long and accurate input data series.

In this work we employ a numerical method for the simulation and optimization of the PV micro-grid which is based on the model shown by Ref. [24]. The physical modeling and the numerical technique have been implemented in MATLAB® which was employed to perform the optimization process. In the following we report the main equations that define the mathematical models of the system components and the technical parameters which have not been described in the paper text.

The simulation of the system and the optimization method consists in three steps. The first step involves the estimation of PV energy output for each time-step of the simulation (t):

$$E_{PV}(t) = PV_{size} * \left(1 - \rho_T * \left(T_{Cell}(t) - T_{Rif}\right)\right) * \frac{H_\beta(t)}{h} * \eta_{BOS} \quad [kWh] \tag{A1}$$

where:

- $H_\beta(t)$ is the specific solar irradiation on tilted surface for the chosen time-step;
- PV_{size} is the rated power of the panels under simulation at an irradiance h of 1 kW/m^2, an ambient temperature of 25 °C and an air mass value of 1,5;
- ρ_T is the temperature coefficient of power respect to solar cell temperature provided by the manufacturer (normally 0.35÷0.45%/°C);
- η_{BOS} is the balance of system efficiency which embraces all the losses not directly related to the sun energy conversion process.

Eq. (A1) also considers the effect of the solar cell temperature (T_{Cell}) on the output of the PV modules. The solar cell temperature at each time-step of the simulation can be calculated by means of the procedure shown in Ref. [43].

The second step describes the battery bank behavior by estimating the amount of energy that flows through the battery and the change in the battery State of Charge. For each time-step the difference between PV array output ($E_{PV}(t)$) and load required by the user ($E_D(t)$) after inverter efficiency (η_{Inv}) is calculated:

$$\Delta E = E_{PV}(t) - \frac{E_D(t)}{\eta_{Inv}} \quad [kWh] \tag{A2}$$

If the difference is positive the battery will be under charge, on the contrary a discharge will occur. Moreover the energy stored in the battery (i.e. SOC) needs to be updated based on the amount previously stored ($E_{Bat}(t-1)$):

$$E_{Bat}(t) = \begin{cases} E_{Bat}(t-1) + \Delta E * \eta_{CH}, & \Delta E > 0 \\ E_{Bat}(t-1) + \dfrac{\Delta E}{\eta_{DISCH}}, & \Delta E < 0 \end{cases} \left[kWh\right] \tag{A3}$$

where η_{CH} and η_{DISCH} are respectively the battery charge and discharge efficiencies. Then, the SOC needs to be updated based on the previously value:

$$SOC(t) = SOC(t-1) \pm \frac{E_{Bat}(t)}{B_{size}} \tag{A4}$$

Furthermore, the energy stored in the battery is subjected to the following constraints:

- to respect a minimum and maximum level of the state of charge ($SOC_{min} - SOC_{max}$);
- to respect the power-to-energy ratio ($(P/E)_R$) of the battery. As a matter of fact, a battery of capacity B_{size} cannot accept or provide every amount of inflow or outflow power. In order to model these features, we consider the power-to-energy ration so that, if for example the $(P/E)_R$ is 0.5 and the B_{size} is 1 kWh, the battery can provide or accept a maximum of 500W for an hour.

The battery lifetime approach used is the *rainflow* cycles counting method, based on Downing's algorithm [44]. This method is based on counting the charge/discharge cycles Z_i corresponding to each range of the Depth of Discharge (split in m intervals) for a year. For each interval there is a number of Cycles to Failure (CF_i) obtained from Fig. A1. Battery duration can be calculated as follows:

$$Life_{Bat} = \frac{1}{\sum_{i=1}^{m} \frac{Z_i}{CF_i}} \quad [year] \tag{A5}$$

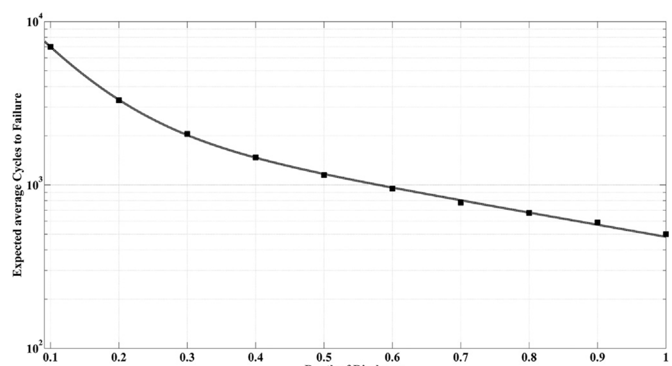

Fig. A1. Cycles to Failure Vs Depth of Discharge for lead acid battery.

The third and final step is the computation of the techno-economical parameters that are employed to look for the optimum system. Here we report the equations to compute the Loss of Load, while for the Loss of Load Probability, the new proposed Net Present Cost, the VOLL, and others the reader should refer to the paper text.

The Loss of Load (LL) indicator represents the amount of energy required by the load that remains unsatisfied because the system is unable to supply enough power. LL is computed during the discharge phase of the battery ($\Delta E < 0$) when one between two conditions occurs:

$$\mathrm{LL}(t) = \begin{cases} (SOC_{min} - SOC(t)) * \eta_{DISCH} * \ \eta_{INV} * B_{size} & SOC(t) < SOC_{min} \\ (\Delta E - (\mathrm{P/E})_R * \mathrm{B}_{size} * \Delta t) * \eta_{INV} & \dfrac{\Delta E}{\Delta t} \geq (\mathrm{P/E})_R * B_{size} \end{cases} \quad [kWh] \tag{A6}$$

Appendix B. Load data assumptions for the micro-grid area in Soroti

Class type	N_{US}	App name	P [W]	N_{App}	h_{funct}	$W_{f,1}$		$W_{f,2}$		$W_{f,3}$		Tot_W
						h_{start}	h_{stop}					
Family_1	50	Lights	3	4	6	0	2	17	24	–	–	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Security Light	5	1	12	0	7	17	24	–	–	14
Family_2	15	Lights	3	4	6	0	2	17	24	–	–	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Security Light	5	1	12	0	7	17	24	–	–	14
		Radio	5	1	4	6	9	17	24	–	–	10
		AC-TV (small)	100	1	5	11	15	17	24	–	–	11
Family_3	15	Lights	3	8	6	0	2	17	24	–	–	9
		Phone Charger	5	2	3	0	9	13	15	17	24	18
		Radio	5	1	4	6	9	17	24	–	–	10
		Security Light	5	2	12	0	7	17	24	–	–	14
		AC-TV (small)	100	1	5	11	15	17	24	–	–	11
		Fridge (small)	250	1	5	0	24	–	–	–	–	24
Family_4	10	Lights	3	12	6	0	2	17	24	–	–	9
		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	1	4	6	9	17	24	–	–	10
		Security Light	5	4	12	0	7	17	24	–	–	14
		AC-TV (small)	100	1	5	11	15	17	24	–	–	11
		Standing Fan	55	1	6	8	24	–	–	–	–	16
		Decoder	15	1	5	11	15	17	24	–	–	11
		Fridge (small)	250	1	5	0	24	–	–	–	–	24
		Internet Router	20	1	6	0	24	–	–	–	–	24
		Laptop (small)	55	1	6	0	2	11	15	17	24	13
Family_5	5	Lights	3	16	6	0	2	17	24	–	–	9
		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	2	4	6	9	17	24	–	–	10
		Security Light	5	6	12	0	7	17	24	–	–	14
		AC-TV (big)	200	1	6	11	15	17	24	–	–	11
		Standing Fan	55	2	6	8	24	–	–	–	–	16
		Decoder	15	1	6	11	15	17	24	–	–	11
		Fridge (big)	400	1	5	0	24	–	–	–	–	24
		Internet Router	20	1	8	0	24	–	–	–	–	24
		Laptop (big)	80	2	8	0	2	11	15	17	24	13
Family_6	5	Lights	3	16	6	0	2	17	24	–	–	9
		Phone Charger	5	4	3	0	9	13	15	17	24	18
		Radio	5	2	4	6	9	17	24	–	–	10
		Security Light	5	6	12	0	7	17	24	–	–	14
		AC-TV (big)	200	1	6	11	15	17	24	–	–	11
		Standing Fan	55	2	6	8	24	–	–	–	–	16
		Decoder	15	1	6	11	15	17	24	–	–	11
		Fridge (big)	400	1	5	0	24	–	–	–	–	24
		Internet Router	20	1	8	0	24	–	–	–	–	24
		Laptop (big)	80	2	8	0	2	11	15	17	24	13
		Hair Dryer	1000	1	0.5	17	24	–	–	–	–	7
		Printer	50	1	0.5	17	24	–	–	–	–	7
		Stereo	100	1	3	17	24	–	–	–	–	7
		Water Heater	660	1	2	0	2	18	24	–	–	8
Enterprise_1	15	Fluor. Tube (small)	36	10	6	7	11	16	20	–	–	8
		Phone Charger	5	4	3	7	13	15	20	–	–	11
		Security Light	5	4	12	0	7	17	24	–	–	14
		Internet Router	20	1	10	7	20	–	–	–	–	13
		Laptop (big)	80	1	8	7	13	15	20	–	–	11
		Laptop (small)	55	5	8	7	13	15	20	–	–	11
		Printer	50	2	2	7	13	15	20	–	–	11
		Standing Fan	55	2	8	7	13	15	20	–	–	11
Enterprise_2	5	Fluor. Tube (big)	47	20	6	7	11	16	20	–	–	8
		Phone Charger	5	15	3	7	13	15	20	–	–	11
		Security Light	5	10	12	0	7	17	24	–	–	14
		Internet Router	20	1	10	7	20	–	–	–	–	13
		Laptop (big)	80	5	8	7	13	15	20	–	–	11
		Laptop (small)	55	10	8	7	13	15	20	–	–	11
		Standing Fan	55	5	8	7	13	15	20	–	–	11
		Water dispenser	550	1	3	7	13	15	20	–	–	11
		Photocopier	750	1	1	7	13	15	20	–	–	11
		Ceiling Fan	75	5	8	7	13	15	20	–	–	11
		PC	400	1	10	7	20	–	–	–	–	13
Mobile Money	5	Lights	3	2	3	8	11	16	20	–	–	7
		Phone Charger	5	3	3	8	18	–	–	–	–	10

(*continued*)

Class type	N_{US}	App name	P [W]	N_{App}	h_{funct}	$W_{f,1}$		$W_{f,2}$		$W_{f,3}$		Tot_W
						h_{start}	h_{stop}					
		Standing Fan	55	1	6	10	18	–	–	–	–	8
Kiosk	10	Lights	3	2	3	8	11	16	20	–	–	7
		Phone Charger	5	1	3	8	18	–	–	–	–	10
		Standing Fan	55	1	6	10	18	–	–	–	–	8
		Fridge (small)	300	1	8	0	24	–	–	–	–	24
		Fridge (big)	500	1	8	0	24	–	–	–	–	24
Barber	2	Lights	3	5	8	8	13	15	20	–	–	10
		12V shaver	10	5	6	8	13	15	20	–	–	10
		Ceiling Fan	75	3	8	8	13	15	20	–	–	10
		UV sterylizer	50	1	2	8	13	15	20	–	–	10
Tailor	3	Lights	5	3	8	8	13	15	20	–	–	10
		Sewing machine	50	1	3	8	13	15	20	–	–	10
		Ceiling Fan	75	1	8	8	13	15	20	–	–	10
Market Place	1	Lights	3	25	3	8	11	16	20	–	–	7
		Security Light	5	25	12	0	7	17	24	–	–	14
		Fridge (small)	300	3	8	0	24	–	–	–	–	24
		Fridge (big)	500	3	8	0	24	–	–	–	–	24
		Standing Fan	55	10	8	8	13	15	20	–	–	10
		Radio	5	10	4	10	13	15	18	–	–	6
Club	3	Fluor. Tube (small)	36	10	8	0	4	17	24	–	–	11
		Fluor. Tube (big)	47	5	8	0	4	17	24	–	–	11
		Security Light	5	5	12	0	7	17	24	–	–	14
		Phone charger	5	10	8	15	24	–	–	–	–	9
		AC-TV (small)	130	2	9	0	4	15	24	–	–	13
		AC-TV (big)	200	1	9	0	4	15	24	–	–	13
		PC	400	1	9	0	4	15	24	–	–	13
		Laptop (big)	80	10	6	15	24	–	–	–	–	9
		Printer	50	1	1	15	20	–	–	–	–	5
		PicoProjector	18	1	4	0	2	20	24	–	–	6
		Amplyfier	6	1	4	0	2	20	24	–	–	6
		Ceiling Fan	75	3	8	0	4	15	24	–	–	13
		Music System	178	1	8	0	4	15	24	–	–	13
		Internet Router	20	1	9	0	4	15	24	–	–	13
		Fridge (small)	300	2	8	0	24	–	–	–	–	24
		Fridge (big)	500	1	8	0	24	–	–	–	–	24
Street Lights	1	Lights (Street)	50	100	12	0	7	17	24	–	–	14
		Led strips	8	100	12	0	7	17	24	–	–	14
Primary School	1	Fluor.Tube (small)	36	10	4	8	17	–	–	–	–	9
		Phone Charger	5	7	3	8	17	–	–	–	–	9
		Security Light	5	4	12	0	7	17	24	–	–	14
Pharmacy	1	Lights	3	10	3	8	11	16	20	–	–	7
		Security Light	5	4	12	0	7	17	24	–	–	14
		Fridge (small)	300	3	8	0	24	–	–	–	–	24
		Fridge (big)	500	2	8	0	24	–	–	–	–	24
		Standing Fan	55	3	8	8	13	15	20	–	–	10

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