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PV integration in minor historical centers: proposal of guide-criteria in post-earthquake reconstruction planning

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Abstract

One of the main challenges in next years will be the retrofit of existing built heritage. Even the most ancient settlements, to avoid the absolute neglect, will have to consider a "contemporary" and environmentally aware vision of refurbishment. In Italian territories hit by earthquake, this challenge is already today a potential for their life return: BIPV, or in general PV implementation, is one of the possible ways to be faced for ensuring a renewable contribution in the perspective of "Nearly-Zero Energy Settlements". The presented study, after synthesizing some main key-strategies for PV introduction at landscape, urban and building scale, focuses on the definition of reference requirements and practical findings useful in the proposal of guide-criteria for urban re-planning of minor historical centers. The outcomes could also be used in the ongoing reconstruction process, for defining innovative and sustainable strategies for PV implementation in minor (nearly-zero energy) historical centers.

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Keywords: BIPV; refurbishment; urban re-planning; sensitive heritage; photovoltaic.

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1. Introduction

Many historical centers, hard hit by the catastrophic earthquake of 2009 in L'Aquila (Italy), have traumatically changed their reality substituting the charming landscape of historical stratifications, with a dramatic collection of voids, collapses and ruins (to be replaced or refurbished). One of the main challenges for the next years will be the

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research of a “contemporary” logic of intervention that won’t have to renounce to a "right" technological contribution as well as to some important reflections about sustainability and energy efficiency of these centers [1]. This issue will be an indispensable paths to be faced in the re-planning process of the historical settlements involved, with the challenge to improve the energetic efficiency of whole urban systems and, where possible, to achieve the “Nearly-Zero Energy Centers” standard in post-reconstruction status. Within this challenging goal, PV by now has an undisputed role in design and planning strategies together with other renewable sources (biomass, wind, water). The PV “integration” in historical areas, nevertheless, differently by ordinary contexts needs a more complex approach linked to the value analysis and to the question of “compatibility” and “controlled transformation" [2]. Although possible ways for PV acceptability in sensitive environment have been already shown [3], the local process complexity, the attention mainly focused on seismic safety and the absence of “objective rules” risk leaving space on simple prohibitions in the contexts concerned, as done so far. The goal of this work is to define basic criteria and strategies for PV implementation at urban and building scale in the re-planning of these minor historical centers, within the methodology of the “compatible” intervention. Although in these contexts we have to recognize the general undisputed role of the “case by case” project, it’s necessary to consider, as a new basic goal, the achievement of new energetic standards besides to other typical requirements (functionality, safety, heritage protection...) especially in cases where a wide and deep reconstruction will have to be faced [4]. The research outcomes, including PV integration strategies, practical findings with reference to some case-studies, could be used by organizations, municipalities, architects and operators (refurbishment design, urban planning, building regulations…) as a guide-tool for defining refurbishment and re-planning processes according to a perspective of a sustainable and compatible solar implementation [5]. This manuscript tries to outline criteria of PV implementation according to a new perspective no more based on the opposition between technology and heritage preservation but based on the wish to outline more compatible and useful integration possibilities of solar technology within an innovative urban process, at the same time eco-sustainable, technologically advanced and in full respect of historical and environmental values of these places.

Nomenclature

BiPV	Building Integrated Photovoltaic
Nearly-ZEB	Nearly-Zero Energy Buildings
RES	Renewable Energy Sources

2. PV within a sustainable re-planning of old urban systems: possible ways of integration

Any intervention on historical settlements, generally opens a cultural and operative relation with the “rules” of the ancient settlements that are consolidated in its intimate nature. Built and open spaces, roads, streets and squares, together form the unitary image of these places, close linked with the topography, morphology and, more generally, with the surrounding natural environment [6]. Overcoming any ideological positions, a sustainable refurbishment/re-planning that is the only way for their return in life, needs a stronger research of “compatibility” between technology and heritage preservation. This intention must quickly move from a methodological preposition towards a real and operative practice. Clearly, within an existing contexts worthy of respect and, accordingly, very different by single buildings of ordinary heritage, solar implementation and PV enter in a peculiar and deeper relationship with “the overall environmental value” of the settlement. The study of PV integration strategies, so, before referring to the building envelope, requires a broader and more complex assessment, which includes open spaces, relation systems and landscape areas. In most cases, likewise, the intervention on a single building becomes an urban or landscape episode. In the meantime, the building-scale needs to be expanded to the building “aggregate” size, typically defined by a homogeneous historical built unit including several houses.

With the objective of fast converting the existing housing stock accordingly to an energy efficiency perspective, in addition to the standard Nearly-ZEB that today is already a feasible reality, the main challenge of the coming years and object of this paper, will be the achievement of the broader and more challenging target of Nearly-Zero Energy Settlement. The building cannot be conceived any more as a close an self-referential unit, but it needs to be intended as an integral part of a more complex system (clusters, grids, city) that is a smart and eco-sustainable settlement where energy efficiency is not given just by the sum of many efficient buildings but, contrariwise, by an innovative interaction among urban areas, mobility, transport, industry, agriculture, waste ... etc.. This topic will also match some ongoing international researches related to “Solar Energy and Urban Planning” [7], [8].

The already stressed disciplinary debate on "how to recover" the historical heritage finds today, in the municipalities of Abruzzo, the urgent need for a deep rethinking. Obviously the intervention on these settlements poses problems of a higher complexity that go beyond a mere respect of regulatory constraints. Depending on the magnitude of the suffered damages, different design aims will be opened ranging from a simple conservation / repairing to the progressive possibilities of layering, adding, prosthesis, interposition up to replacement with new. Anyway the energy efficiency goal will have to be considered one of the basic rules to be introduced and, in this perspective, the implementation of solar renewable energies such as PV will have to be broadened both at "urban-landscape” and “aggregate-building” scale [1], [5]. A new way of thinking about renewable energy in landscaping environment is shown, for instance, by movements and initiatives of Land Art which have demonstrate a creative and artistic way to use renewable sources and technologies in harmony with nature [9], [10]. Furthermore, at building scale, some industrial prototypes are opening very interesting and revolutionary scenario about an “invisible” photovoltaic hidden behind tiles and stones, in a mimicry way [11]. Also other innovations such as luminescent solar concentrators (LSCs) open new ways for PV re-thinking in high sensitive contexts. In other cases where a significant renovation of building or a whole replacement is possible, there are chances for PV integration accordingly to the principles of a compatible and "distinguishable" solar re-design and re-shaping of existing.

3. PV integration in reconstruction process: input for guide-lines from landscape to building scale

3.1. Performance framework of assessment

This part of research is aimed to define a first list of requirements useful for the preparation of a guidance scheme that promotes good siting and design of solar PV in urban environment and landscape. The guidance, potentially deriving from these criteria, should outline how solar implementation may be accommodated minimizing impacts to existing environment and protecting the recognized values, besides to add renewable energy supply to the refurbished settlements. The guidance could be used by a range of audiences such as planning authorities and solar PV developers, as well as by several stakeholders involved in the reconstruction/refurbishment process. In some best practices of territory planning, some tools and guide-lines regarding the evaluation of environmental compatibility of PV solar plants already may be taken as a useful reference [12], [13]. These tools contains interesting evaluations of PV environmental compatibility, in particular for free-standing PV at a landscape-field scale (from about 1 ha to 15 ha), in relation to location and installation criteria, construction, use, management and dismissing phase as well as in relation to the definition of specific mitigation and compensation measures. The visual impacts of solar PV fields are likely to be amongst the most significant impacts in an area with a large percentage of sensitive heritages. The reflection of land-form, land-cover, scale and pattern of the landscape as well as the historic pattern of fields have to be evaluated due to avoid any negative impact on landscape character. The impact of complementary construction should also be included. Without any regulation developers would be attracted to southerly sloping sites, where solar gain is greatest. However such sites might be of high agricultural value and or could be more visible within the wider landscape. Accordingly any development (fencing, security, cabling, electricity grids…) need to have regard to its design, layout and future maintenance plans.

Starting from this state of art mainly focused on solar fields, the research broaden some general requirements for PV implementation in urban/building scale in historical settlements. The basic idea is to consider minor historical centers as a whole where built heritage, open areas and surrounding landscape forming a unitary part that cannot be distinguished or separately considered. In this way, therefore, any part of these settlements can be seen as a landscape part that can be evaluated with its same methods, properly re-adapted. It’s therefore possible to develop an urban impact assessment (UIA) at urban or aggregate size. Differently by a typical Environmental Impact Assessment (EIA) process, for the planned aims, the proposed list (Table 1) does not regard specific ecological issues associated with nature conservation or cultural heritage/archaeological issues that would need to be taken into account through a more complex process and according to existing laws.

Table 1. List of reference requirements for PV integration at aggregate, urban and landscape scale

Scale of intervention	*Refurbishment post-earthquake strategies*	*Analysis steps for PV integration*
Building-Aggregate	Repair (Strengthening) Consolidation (Improvement) Replacement (Retrofit)	Character, quality and sensitivity analysis (Aggregate/building transformability ratio)
Single houses Historical aggregate *Earthquake damages* From low to very high (collapses)		*Aggregate-buildings form and characters* *Sense of openness/enclosure (site visibility)* *Historic urban character (sensitivity of heritage)* *Scenic, perceptual and special qualities (urban/architectural beauty)* *Zone of theoretical visibility (ZTV)*
Transformability ratio From preservation to a total rebuilding		Detailed layout and design of PV plant (general and component design)
		• Solar design of cells, modules, structures, etc., BiPV *• Location of cables, inverters, etc.*
Urban		Urban character, quality and sensitivity analysis (transformability ratio)
Open/relation spaces Squares Voids (collapses) Networks/Streets	Urban Reconstruction	*Urban form , Sense of openness/enclosure (site visibility)* *City pattern and scale of open/built spaces* *Perceptual quality (natural or artificial)* *Historic urban character (sensitivity of heritage)* *Scenic and special qualities (urban/architectural beauty)* *Zone of theoretical visibility (ZTV)*
Earthquake damages From low to very high (collapses)	Urban Redevelopment	PV siting analysis (Urban visual impact assessment, UVIA)
		Minimizing urban and visual impacts conceiving a PV integration as an enhancement of urban qualities
Transformability ratio From repair to total rebuilding of urban areas, streets, grids		Detailed layout and design of PV plant (general and component design)
		The objective is to design a PV system according with the transformability ratio of urban space. Generally micro-interventions of furnishing or urban design are required considering: *• Solar design of cells, modules, structures, etc.* *• Location of cables, inverters, storage systems, etc.*
Landscape		Landscape character, quality and sensitivity analysis (Landscaping transformability ratio)
Type of areas: Margin areas Green valleys		*Land Form (topography)* *Sense of openness/enclosure (site visibility)* *Field pattern and scale Land Cover and soil (land uses)* *Perceptual quality (natural or artificial activity)* *Historic landscape character (sensitivity of heritage, natural beauty)* *Zone of theoretical visibility (ZTV)*
Transformability ratio Energy Re-planning		PV siting analysis (Landscape Visual Impact Assessment, LVIA)
		Energy Infrastructure (cable passages, grid distance) *Service area/buildings (streets, technical volumes…)* *Soil usage (fence typology, soil covering, agricultural use)* *Foundation typology (reversible), PV structures (height, type, material)* *Cleaning and management of plant* *Acoustic, lighting, electromagnetic impacts*
		Construction and dismissing phases impacts
		Construction time and ways, Digs, traffic, accesses *Recycling/recover of materials at the end of life*
		Detailed layout and design of PV plant at landscaping scale (general and component design)
		The objective is to design a PV system according with the degree of transformability of Landscape considering: *• Layout and number of panels/arrays (including extent);* *• Site access and transporting panels to site;* *• Location of cable and construction compounds, energy stations;* *• Land management changes*

3.2. Preliminary affordability evaluation

After definitely investigating the methodological and practical aspects that today are still the main barriers to solar implementation in sensitive settlements, next steps of research have had the goal to evaluate the energy yield and the demand satisfaction ratio distinguishing the kind of PV technology, the scale and the type of integration. Given the high variability of the contextual conditions for each place, as typical of historic villages, further investigations should have to be applied on different significant case-studies to be carefully analyzed and compared, also assessing the affordability and the effectiveness of solar implementation both from an energetic and economical point of view, considering the whole of built areas, open and public spaces and the surrounding landscape areas.

A first experience recently done on PV integration in urban voids caused by earthquake collapses [5], for instance, has shown that the footprint of urban voids, thanks to the small scale of the nearby buildings (generally of 2 or 3 storeys), seems to be able to locally offer energetic surplus to several nearby houses. It would mean that the implementation of solar systems just in strategic open areas, controlling the urban density and the balance between buildings and voids in the urban re-planning, could be a way to supply the energetic demand (or anyway a significant part) of entire clusters, enhancing the urban liveability with more open areas and avoiding the solar integration on historic buildings. But is this realistic if applied to the whole settlement?

Wanting to initially outline a preliminary evaluation of affordability, some simplified calculation have been done about energy demand and solar potential (in terms of occupied areas, requested power and economy), in relation to different hypothesis of PV implementation. The hypothesized scenario considers some reference data representative of Sant'Eusanio Forconese, that is a small historic center nearby L'Aquila (Fig. 1).

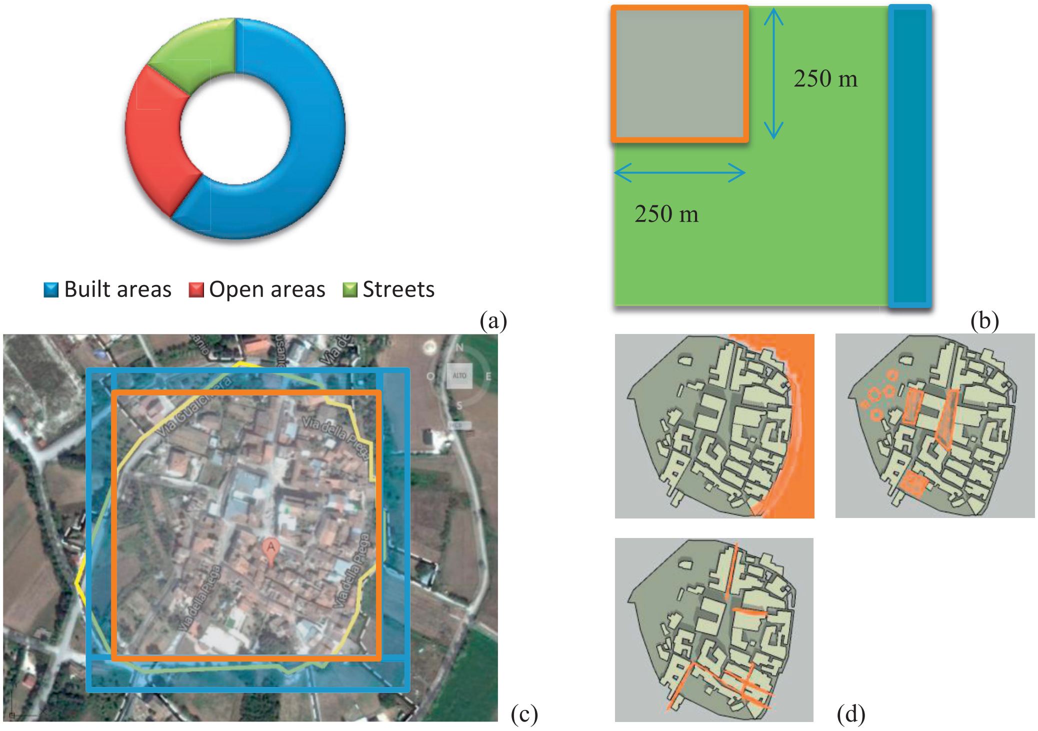

Fig. 1. Data of case-study considered. (a) Different percentages within the built settlement (built areas:60%; open areas:25%; streets:15%) ; (b) Urban area, landscape and PV relationship (built perimeter:62,500 m^2; PV footprint 31,000 m^2; surrounding green area 150,000 m^2). (c) The equivalent area of the historical built perimeter considered for the calculation of solar potential is the central square and, proportionally, PV footprint on territory is displayed around. (d) Landscape surrounding area, open areas and streets within the historical center are highlighted.

On this case-study the energy demand and the PV potential are calculated accordingly to the following hypothesis and considerations. The scenario considers the only use of solar PV technology, excluding a renewable sources mix in this preliminary evaluation although this wouldn't be always feasible in reality. Both the demand and potential calculation of the whole settlement have been done in a simplified way for the purpose of this assessment.

The demand has been simply established considering energy consumption coefficients typical of residential and public buildings and determining the total energy amount in proportion to the relative surfaces, with the hypothesis of all two-storey buildings. Obviously, wanting to quantify an equivalent electrical amount of energy, the heating and cooling energy requests should be converted in an equivalent electric load. Nevertheless, as following showed, considering the Italian energy mix and the hypothesis of a higher efficiency of electrical heat pumps compared to gas boiler we can consider, for the simplified purpose concerned, the same value of kWh.

Table 2. Conversion factor between electrical and thermal energy loads

Electrical Energy (Italian Mix)
1 kWh (electrical mix) = **0,187 x 10 $^{-3}$ TEP** (EEN 3/08, Italian Authority for electrical energy and gas)
5,347 kWh (electrical mix) = **1 TEP**
Typical efficiency of gas boiler for heating: 0,95

Thermal Energy (Natural gas)
1,000 m^3 natural gas = **0.82 TEP** (Ministerial Circular 219/F, 02.03.1992)
11,628 kWh (thermal, natural gas) = **1 TEP** (Ministerial Decree 20.07.2004)
Typical average efficiency of cheap electrical heat pump (C.O.P.): 2.5

Conversion Energy factor: **1 kWh (electrical) = 2.17 kWh (thermal)**
Conversion Energy factor, corrected with efficiency: 1 kWh x 2.5 (electrical) = 2.17/ 0.9 kWh (thermal) that is **2.5 kWh,el ≃ 2.41 kWh,t**

Other energy electrical demands about mobility or urban lighting have been parametrically calculated. For an e-bike a yearly consumption of 25 kWh is considered and for an electric car a demand of 1,500 kWh/year. The energy demand summary is reported in the tab.3.

Table 3. Energy Demand of the settlement

						Heating and hot water		Electrical loads	
		storeys	% territory	Territory Footprint m^2	Surface m^2	Coefficient (kWh/m^{2}y)	Energy demand (MWh/y)	Coefficient (kWh/ m^{2}y)	Energy demand (MWh/y)
Center	Private Buildings	2	60	32,500	65,000	60	3,900	20	1,300
	Public buildings	3		5,000	15,000	120	1,800	75	1,125
	Open areas	-	25	15,625	15,625	-	-	5	78
	Streets	-	15	9,375	9,375	-	-	8	75
Landscape		-		150,000	150,000	-	-	-	-
Mobility and smart grids (50 cars + 50 e-bikes)		-	-						76
TOTAL DEMAND							8,354 MWh/year		

Regarding PV technologies the following types have been considered:

- Thin Film technology (TF), with a power density of 100 Wp/m^2 corresponding to the average behavior of a CIS module (module efficiency: 10%);
- Crystalline silicon technology (CR), , with a power density of 210 Wp/m^2 corresponding to the average behavior of a mono-crystalline silicon module (module efficiency: 21%).

The energy production considers different PV integration capacity for landscape or urban areas, taking into account in a qualitative way diverse transformability potential in relation to their values and damages suffered. A first conversion factor, that is a transformability degree (TD), has been used in the consideration of the really available surfaces for PV integration in each context. In landscape areas, considering the presence of fields (agriculture) and the presence of beauty scenery worthy of protection, a TD=25% of the available surface is considered compatible for PV implementation. Within urban center, likewise, 30% of open areas (squares, urban voids…) and 10% of streets are considered available taking into account the high sensitivity of urban environment and the complex morphology and topography of the settlement that are not always compatible with PV integration.

Finally, considering the wide damages due to the earthquake, a 20% of buildings is considered available for PV integration in a perspective that at least a such percentage will be rebuild of refurbished according to innovative architectural solutions (differently by "where it was like it was"). Furthermore, taking into account the average conditions about optimal inclination, exposure, shadows, ventilation, transparency and PV density, a second percentage value, called density factor (DF) has been introduced weighting the energy usability of the available surfaces. In many cases, such as streets or urban open areas, in fact, often PV is limited to local devices or urban furnishing, representing a limited part of the physical environment (15% for streets and 20% of open areas), differently by landscape solar field or building's roofs where PV density is much higher (50% for buildings and 70% for landscape). An analysis on PV potential has been done as briefly described in the following table n.4.

Table 4. PV available surfaces and Energy Potential

						THIN FILM		CRYSTALLIN	
	Yearly PV potential kWh/kWp	Territory Footprint m^2	TD %	DF %	PV Surface m^2	Power (kWp)	Energy production (MWh/y)	Power (kWp)	Energy production (MWh/y)
Private Buildings	1,100	32,500	20	50	3,250	325	357	682	750
Public buildings		5,000	20	50	500	50	55	105	115
Open areas	800	15,625	30	20	935	93,5	74.8	196	157
Streets	700	9,375	10	15	141	14.1	9.8	29	20
Landscape	1,000	150,000	25	70	26,250	2,625	2,625	5,512	5,512
TOTAL							**3,122**		**6,554**

In the first hypothesis, above reported, PV implementation in building, open areas and marginal landscape areas is able to satisfy from 37% to 78% of demand, depending on PV technology. The trend for different scenario (private and public buildings, open areas, streets, landscape, mobility) is reported in the fig. 2. The major demand is obviously requested by buildings and the main PV potential, in the mentioned hypothesis, is related to the availability of landscape areas. In a second hypothesis where buildings are considered refurbished in a very efficient way, with energy performance index assumed of 30 kWh/m^{2}y for private buildings and 80 kWh/m^{2}y for public ones, the modified scenario is showed in fig.3. In this case the hypothesized PV implementation (and in particular the landscape solar field of about 26 ha) is able to almost completely satisfy the settlement energy demand with a percentage of 92% in the thin film hypothesis or having a 183% surplus in crystalline case (fig. 4).

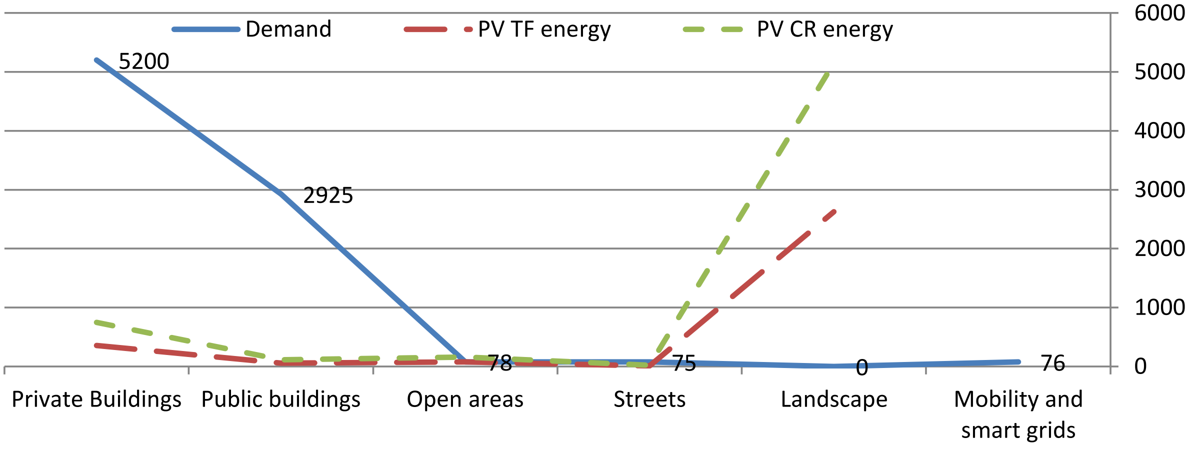

Fig. 2. The graphic shows the energetic values (Y axis, MWh) of demand and PV production (thin film and crystalline technologies) for different typologies of buildings, urban spaces and landscape of the settlement (X axis). The major demand is requested by buildings and the main PV potential, in the mentioned hypothesis, is related to the availability of landscape areas.

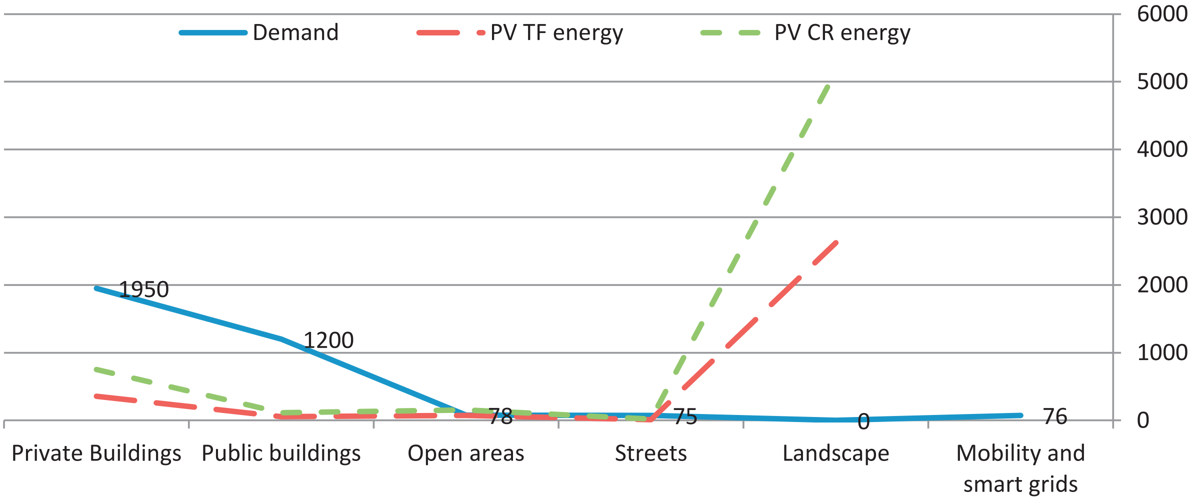

Fig.3. The graphic shows the energetic values (Y axis, MWh) of demand and PV production (thin film and crystalline technologies) for different typologies of buildings, urban spaces and landscape of the settlement (X axis), in the hypothesis that buildings are refurbished in a very efficient way. The PV potential is able to satisfy energy requirements of the settlement.

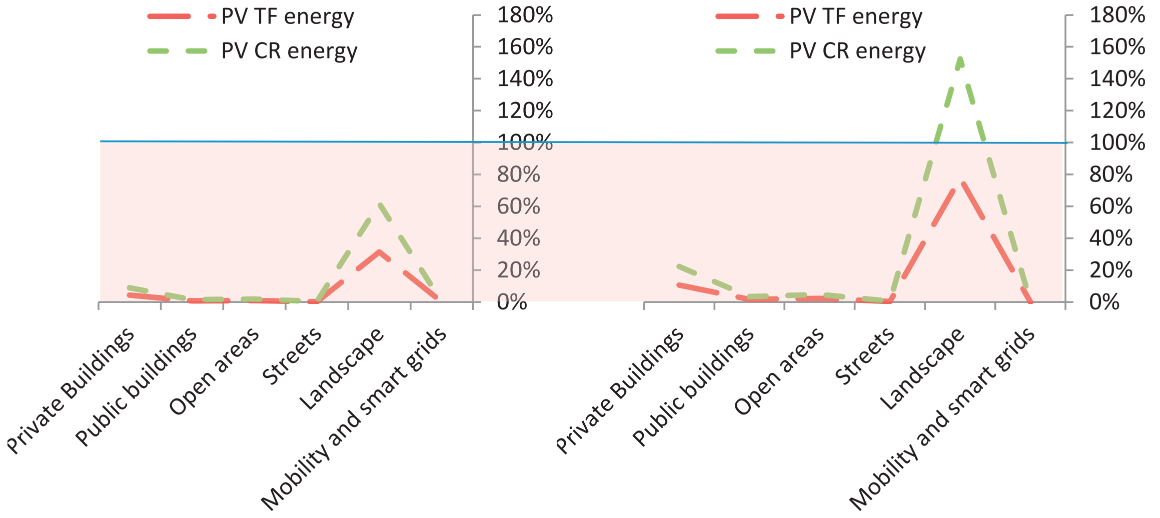

Fig.4. The graphic shows the satisfaction percentage (Y axis) of energy demand operated by PV systems integrated at building, urban and landscape scale. This is expressed by the ratio between PV energy production and total energy demand calculated for the historic settlement. Two scenario are reported: the first one (left) considers a typical building energy consumption (Table 4); the second one (right) considers a high-efficiency of built environment (30 kWh/m2y for private buildings and 80 kWh/m2y for public ones instead of 60 kWh/m2y and 145 kWh/m2y). Considering that the major part of energy consumption is related to buildings, the second scenario shows the ability of PV to satisfy the main part of energy demand or the whole demand (depending on solar technology), according to a Nearly-zero Energy or Plus-Energy settlement.

Therefore, considering the above scenarios, the research findings show that a premeditated re-planning of urban settlements introducing a significant PV implementation, allows satisfying a main part of the energy request according to the standard of Nearly-Zero Energy Center. Obviously in cases where the transformability is lower (e.g. within the historical settlements and/or in landscape areas) the energy strategy could become an energy mix with other RES (biomass, cogeneration, thermal solar, hydro, wind, etc.). Anyway the PV implementation scenario appears also economically sustainable especially considering the reconstruction costs in most of these centers. In Tables 5 and 6 a synthetic economic evaluation is reported. Table 7 shows that PV costs for completely supply energetic demand of the settlement would represent a limited percentage of whole reconstruction costs (around 10%, considering a Pv technology mix) and moreover they would have a pay-back time, differently by other costs. It has to be considered that grids and undergrounds services will have to be replaced during the reconstruction process and therefore some costs about grid, connections, services, etc, could further be reduced. A variable cost of PV installation ranging from 2.3 to 3 €/Wp is considered as well as an electric fee of 0.20 €/kWh, according to the typical Italian current market. PV costs are compared with reconstruction costs (public and private buildings, public spaces and grids) as evaluated in the reconstruction plan of the municipality [14], that is about 105 € million.

Table 5. Economic evaluation about PV implementation in the settlement (hypothesis TF)

	THIN FILM								
	Energy demand (MWh/y)	PV Power (kWp)	PV Energy production (MWh/y)	PV costs (€/kWp)	Fee (€/kWh)	PV Cost (M€)	Money saving (M€/y)	Pay back time (years)	% reconst costs
Private Buildings	5,200	325	357	2,500	0,20	0.812	production lesser than demand 3,122 x 0,2		
Public buildings	2,925	50	55	3,000	0,25	0.150			
Open areas	78	93.5	74.8	2,500	0,20	0.233			
Streets	75	14.1	9.8	3,500	0,20	0.049			
Landscape	-	2.625	2,625	2,100	-	5.512			
TOTAL	**8,354**		**3,122**			**6.756**	**624**	**9.8**	**6.4**

Table 6. Economic evaluation about PV implementation in the settlement in the scenario of Zero-Energy Center (hypothesis CR + high efficient buildings)

	CRYSTALLINE								
	Energy demand (MWh/y)	PV Power (kWp)	PV Energy production (MWh/y)	PV costs (€/kWp)	Fee (€/kWh)	PV Cost (M€)	Money saving (M€/y)	Pay back time (years)	% recons costs
Private Buildings	1,950	682	750	2,500	0.20	1.705	production lesser than demand 6,554 x 0,2		
Public buildings	1,200	105	115	3,000	0.25	0.315			
Open areas	78	196	157	2,500	0.20	0.490			
Streets	75	29	20	3,500	0.20	0.101			
Landscape	-	5,512	5,512	2,100	-	11.575			
TOTAL	**8,354**		**6,554**			**14.186**	**1.310**	**10.9**	**13.4**

Table 7. Economic evaluation about PV implementation in the settlement in the scenario of table 3 and 4 (respectively thin film and crystalline PV with high-efficient buildings). The PV costs are compared with costs that will be required for post-earthquake reconstruction of the settlement. PV implementation with the goal of a Zero Energy center would cost about a 10% of the total amount and would have a pay-back time of around 10 years just considering the money saved for electricity by community. Furthermore, using incentives for RES, the investment (private and public) could be much more convenient. It has also to be considered that costs about grids and infrastructures are already included in reconstruction costs and, so, estimated PV costs could additionally include other services (smart grids, storages, etc.)

		THIN FILM COST		CRYSTALLIN COST		RECONSTRUCTION
	PV Surface m^2	Power (kWp)	PV Cost (M€)	Power (kWp)	PV Cost (M€)	Post-earthquake reconstruction costs (M€)
Private Buildings	3,250	325	0.812	682	1.705	91.76
Public buildings	500	50	0.150	105	0.315	4.50
Open areas	935	93,5	0.233	196	0.490	8.68
Streets	141	14.1	0.049	29	0.101	
Landscape	26,250	2.625	5.512	5.512	11.575	-
TOTAL			**6.76**		**14.19**	**104.94**

4. Conclusions

The paper reports criteria and evaluations aimed to define the main topics about PV solar implementation in historical settlements that will have to be refurbished after the earthquake of 2009 in Italy. In the first part a first list of requirements useful for guide-criteria has been defined. In the second part a preliminary evaluation of affordability has been done on a case-study center, in relation to energetic and economical aspects. In a simulated scenario PV is integrated within the historical settlement (on a certain percentage of buildings and open areas footprint, respectively of 20% and 30%) and on nearby landscape (a 26.000 m^2 solar field has been considered corresponding to about 40% of settlement footprint). Emerging that the energy demand mainly depends on private buildings consumption, the energy-efficiency criteria with which they will be refurbished are the influencing parameter. In the hypothesis of high-efficient refurbishment/replacement of damaged buildings (total energy demand of private buildings of 30 kWh/m^2y), the proposed PV layout is able to achieve the standard of Nearly-Zero Energy Settlement, satisfying the whole energy demand just through solar energy. The PV footprint on territory would be around 31,000 m^2 (including landscape, open and built area), in the hypothesis of crystalline technology, totally representing the 50% of the historical perimeter footprint (62,500 m^2), but with a PV concentration within the historic built of just 4,800 m^2 that is less than 8% of surface (including PV on buildings, streets and open areas). Adopting these low density of PV within the built settlements (in the hypothesis of high value to be preserved that is a low transformability of buildings), the need of solar field in landscape areas is requested. Without a solar field, in fact, the amount of energy demand satisfied by PV installed within the historic perimeter would be just a 6% (these amount depends on refurbishment policy and could also increase). Considering the very high costs that will be necessary for reconstruction and the deep interventions that will have to be done in these settlement in the next years, of course a policy strongly linked to energy efficiency, sustainability and RES will be an unquestionable topic for optimizing resources and quality. PV, in this perspective, shows innovative, affordable and compatible potentials to be integrated both from a cultural and practical point of view. Obviously, in this context, once assessed the general topic as done in this paper, the “integration project” needs to be solved in a “craft logic”, not in the sense of the use of traditional systems, but as an artisanal “capacity” of architects, urban planners and municipalities to creatively elaborate potential and opportunities at local scale, case-by-case taking care for compatibility and contextualization of any intervention.

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