

# An Integrated Assessment Model on Local Aptitudes for Green-Energy Self-sustainability



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**Abstract** The Encyclical Letter *Laudato Si* of the Holy Father Francis on “Care for our Common Home” holds human society responsible for the achievement of a fairer world, through research into solutions to environmental problems and a moderate and efficient use of nonrenewable resources. It recalls that energy usage is one of the major factors of environmental pressure and shares the crucial questions of current European and international energy policies. In Italy, for the electric sector, energy policy requires the increase of energy production by renewable sources and the development of a transmission grid able to support a diffused and non-programmed production of electrical energy (a smart grid), as it is the case for energy production through photovoltaic power stations near the consumption centers. In this line, the present paper proposes an evaluation model for verification of local aptitudes for green-energy self-sustainability based on the use of photovoltaic technology built on surrounding, abandoned agricultural land. The model combines the analysis of geo-referenced data, elaborated by the GIS tool, providing knowledge of the territory and the verification of technical feasibility of the diffused power stations, and financial analysis of the project. The application of the model to a case study confirms that it could be useful for local governments in planning energy self-sustainability interventions and in the negotiation phase of project financing.

**Keywords** Integrated evaluation · Solar rent · Energy self-sustainability  
Periurban areas · GIS · Renewable energy · Financial feasibility

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# 1 The Energy Question in the Encyclical Letter *Laudato Si*

The Encyclical Letter *Laudato Si* recalls human society to its responsibility for the achievement of a fairer world. This moral question does not require a merely economic intervention, since the world is a whole entity in which interconnections among human activities, social, culture and natural systems do exist (Francesco 2015, § 6 and Fusco Girard et al. 2014). As the degradation of natural environment and the overconsumption of natural resources have serious consequences on human life, it reminds us that finding solutions for environmental problems is a compulsory course (Francesco 2015, § 110).

Among the various negative effects deriving from the imbalanced relationship between human societies and the environment, the global warming and the consequent climate change particularly are worrying, since their effects have repercussions on socioeconomic systems all over the world, mainly damaging people lacking in economic means to adapt themselves to extreme climate impacts (Francesco 2015, § 25; IPCC 2014). A moderate and efficient use of nonrenewable resources is required in order to limit the negative climate phenomena (Francesco 2015, § 26), contrast the growing “Decline in the quality of human life” (Francesco 2015, Chap. IV, Sect. IV) and the “Global inequality” (Francesco 2015, Chap. IV, Sect. V) and aid “Justice between the generations” (Francesco 2015, Chap. IV, Sect. V).

Analogously, the impacts on human health and quality of life and climate change—with its distributive impacts on poor populations and its damaging effect on rural, natural and urban areas (heat waves, extreme precipitation and storm events, inland and coastal flooding, landslides, increased drought and water scarcity) (IPCC 2014)—are the foundation of international energy policies (United Nations 2015), together with the need to combat and handle the critical issues related to energy supply in many countries (International Energy Agency 2015).

The global nature of the ecological challenge requires a common effort, since isolated actions of single countries are not enough (Francesco 2015, § 164). But, although the complexity of the energy question passes over the possible contribution of single communities, an effective opposition to greenhouse emissions requires the participation of all (Francesco 2015 § 219).

The same perspective is assumed in the present work focusing on the possibility that the numerous towns with low energy consumption can contribute to the cut in non-renewable energy production by an accessible effort. In particular, we propose an integrated evaluation model to define projects for self-sustainability of the territory on a town scale, using abandoned agricultural or at-risk-of-forsaking lands for the installation of photovoltaic power stations. The model integrates a technical analysis, based on a Geographical Information System (GIS) tool and on multi-criteria analysis, and a financial feasibility analysis.

## 2 Normative and Theoretical References on the Energy Question

Although the need for a global commitment of all nations of the world has been proclaimed since 1972 (United Nations 1972), as yet, the energy policies adopted did not prove capable of confronting efficaciously the climate-change phenomenon that is still a current object of international policies (United Nations 2015).

The Encyclical Letter *Laudato Si* is consistent with recent European and international energy policies, whose main objectives are an increase in the use of renewable energy, greater efficiency of the energy system (European Union 2011) and the reduction of greenhouse-gas production to levels within the Earth's carrying capacity (United Nations 2015).

Most European countries adopted national energy policies in compliance with these directives. For example, the Italian energy policy, which is fixed by the National Action Plan for Renewable Energy (2010) and the National Energy Strategy (SEN) (2013), requires increasing recourse to renewable energy sources and the development of a transmission grid able to support diffused and nonprogrammable production of electricity (smart grid), as is the energy obtainable from photovoltaic power stations nearby the consumption centers.

As already stated, the present work proposes an evaluation model for technical and financial definition of plans for municipal electric self-sufficiency based on the use of photovoltaic technology. The focus on electric power derives from the fact that in many countries the gross production of this kind of energy is still obtained using thermoelectric power stations fed with fossil sources. For example, in Italy, traditional power stations produce about 61% of electric power (Ministero dello sviluppo economico 2016). The proposed evaluation model supports the design of energy self-sufficiency projects and participates in the broad field of experimentation on local energy planning (Patlitzianas and Christos 2011; De Mare et al. 2013; Morano et al. 2015) and integrated evaluations.

Integrated evaluations are recognized as tools able to consolidate fundamental knowledge for design and planning on various geographical scales (Ravetz 2000; Bammer 2005; Lee 2006; Mondini 2009; Fusco Girard et al. 2014) according to three main interpretation: an overall assessment of economic, social and environmental impact ("horizontal integration of assessments"); a use of previous evaluation findings regarding decision making in the planning process ("integration of assessments into decision-making"); and a joint use of distinct assessments undertaken at various stages of the project/planning process ("vertical integration of assessments") (Lee 2006). Integrated assessments have been widely used in various fields and sometimes in conjunction with spatial analysis, to support planning and design decisions (Fusco Girard and De Toro 2007; Cerreta et al. 2012; Ferretti et al. 2014; Oppio et al. 2015; De Mare et al. 2015; Leman et al. 2016). In particular, energy-related integrated assessments have concerned multi-regional, long-term energy planning (Koltsaklis et al. 2015), the management of life cycle CO<sub>2</sub> emissions from a building (Roh and Tae 2017), a solar-thermal electricity project

(Rodríguez-Serrano et al. 2017), a small rooftop PV-grid-interconnected energy system (Sagani et al. 2017), an energy-supply system for an energy-efficient building (Džiugaitė-Tumėnienė et al. 2017), the photovoltaic power stations in comparison to other electricity-production technologies (Lo Piano and Mayumi 2017), and the analysis of several energy-system variants for urban communities energy self-sufficiency based on renewable-energy resources (Petersen 2016). In this paper, electric self-sufficiency of small towns based on photovoltaic power stations in surrounding rural areas with low rental costs is dealt with.

Towns located in areas with a high “solar rent” (Granata 2010; Granata 2014), that is an original and natural energy endowment of the place, and whose economies have a low energy demand, can easily achieve a great local production of energy from renewable sources. We propose the photovoltaic use of agricultural lands with a very low cadastral income but a high “solar rent” as a possible contribute to the achievement of the more sustainable word hoped by the Encyclical Letter *Laudato Si* (Francesco 2015 § 13 and 18).

Due to the low entropic impact of its life cycle (Coiante 2004), photovoltaic technology is compatible with the critical role that the second law of thermodynamics plays in the economic context (Georgescu-Roegen 1971; Daly 1974), in the system of values of sustainability (Rizzo 1999) and in the conservation of natural capital, whose services are essential for human life and economy (Costanza et al. 1997). Furthermore, local energy production by renewable sources commensurate with the needs of the settled community respects the fundamental principle of self-sustainability (Fusco Girard and Nijkamp 1997). It also increases the energy efficiency and the local energy independence; preserves the functions of soil in natural cycles; does not generate irreversible transformations of the soil (Coiante 2004); and creates a new form of positive dependence of urban areas on the agrarian ones (Lo Piccolo 2009).

### 3 The Proposed Assessment Model on Local Green-Energy Self-sustainability

In consideration of the above recalled spiritual, normative and scientific references, an integrated assessment model on local aptitudes for green-energy self-sustainability is proposed. The evaluation model, on a municipal scale, is aimed at giving technical and financial information for the design of a diffused power plant for the local self-production of energy requirements by photovoltaic technology. It concerns the use of a part of agricultural lands, characterized by a very low cadastral income, for the installation of photovoltaic power plants, consistent with the constraints in force.

The model is articulated by the following phases.

1. Assessment of the local demand for energy. The electric energy demand is estimated on the basis of statistical data on economic and residential sectors and

on the needs of public buildings. The energy demand for the transport of people and goods has been ignored, since the conversion to the electric source would require the replacement of the entire fleet of vehicles.

2. Definition of the technical criteria for the choice of rural areas that can be used for solar-power plants. There are ambient context constraints, which are the technical criteria proper to territorial planning and engineering technical criteria connected to the installation of photovoltaic power stations.

The ambient context constraints adopted are those prescribed by the Italian Ministerial Decree, September 10, 2010 entitled “Guidelines for the authorization of plants powered by renewable sources”. The legislator establishes the criteria for the exclusion of areas in order to limit the consumption of fertile agricultural land and/or intended for specialty crops, to ensure hydro-geological safety and to protect the historical, archaeological, artistic and cultural heritage and the landscape.

After identifying a first set of suitable rural lands on the basis of the ambient context constraints (low-fertility/profitability and lack of hydro-geological, archaeological, historical, artistic, cultural and landscape bonds), relevant technical engineering criteria will be used to discern among them the most suitable lands for photovoltaic energy production. The engineering technical criteria adopted in the proposed model are the availability of solar radiation corresponding to the local geomorphology and the distance from the local system of the electricity-network infrastructure. The former affects the energy production of photovoltaic plants, while the latter influences the cost of connection of plants to the electric grid.

3. Analysis of the local rural land, aimed at the identification of suitable areas from the point of view of the ambient context. This analysis is carried out using a cognitive model based on the use of geo-referenced data processed by the GIS tool. The territory is analyzed in the light of the ambient-context constraints, related to landscape and to ecological, hydrological, productive and agro-cultural factors. The critical lands can be filtered out by the analysis of these constraints, enabling the analyst to identify a set of “suitable areas”.
4. Application of a multi-criteria procedure on suitable areas for their further selection on the basis of the abovementioned technical factors relevant to the installation of photovoltaic plants. The overall engineering technical performance of the first set of “suitable areas” is assumed to be the weighted sum of the marginal performances with respect to the relevant criteria that are distances from existing energy infrastructures and the micro-local levels of solar irradiation. The overall engineering technical performances of areas assign a ranking of the set of suitable areas. Geo-referencing of ambient-context constraints, together with consideration of technical characteristics of the territory and the structure of the existing electric grid, provide the necessary knowledge to identify the “most suitable areas” for the installation of photovoltaic plants to fulfill the local demand for energy.

5. Qualitative assessment of selected areas in light of the inter-visibility criterion. The current process of construction of new “energy landscapes” (Angelucci 2011) outlines the need for specific evaluation instruments for the design of energy exploitation of lands, reflecting awareness of the dependence of landscapes by energy innovations. The inter-visibility analysis is intended to exclude areas with a high level of visual exposure from the use of photovoltaic energy production. Areas identified and ranked on the basis of the above described process will be used for photovoltaic plants installation only if they meet the low inter-visibility requirement.
6. Financial pre-feasibility analysis. It analyzes economic and financial aspects related to the system of photovoltaic plants for the energy self-sufficiency of towns. It is aimed at clarifying the economic and financial sustainability of photovoltaic plants installed in the areas identified by the previous process. For this purpose, a computerized sub-model for financial analysis must be implemented. It applies the Discounted Cash Flow Method. Net cash flows generated by the project in the various periods of time are used to calculate several profitability indicators (Net Present Value, Internal Rate of Return, Discounted Pay Back Period). The preliminary financial analysis is accompanied by a sensitivity analysis in relation to the financing structure. It creates the basic knowledge for the determination of: the actors who may be involved in the operation (private lenders, financial institutions, companies, local governments) (Stanghellini and Copiello 2011); the financing structure of the project; and the business plan of the project (Caselli and Gatti 2005).
7. Assessment of the avoided production of CO<sub>2</sub> that is recognized as one the main greenhouse gases. It supplies a measure of the environmental benefit of the electric self-sufficiency project.  
In short, the model permits the identification of suitable rural areas for the achievement of a total or, eventually, partial energy self-sufficiency of users in a given town. At the same time, these areas must fulfill the requirements of a low land rent, suitability according to the technical criteria of territorial planning, low visibility and technical suitability for energy power photovoltaic plants. Technical analysis is integrated by a financial pre-feasibility analysis and an assessment of the avoided production of CO<sub>2</sub>.

In Sect. 4, the assessment model proposed is tested in a real case.

## 4 The Case Study

### 4.1 *The Town Studied and Estimation of Local Demand for Energy*

Motta Sant’Anastasia is a town in the province of Catania (Italy) covering about 3,550 ha. Surrounding the built-up area, there are extensive agricultural lands partly

abandoned and partly occupied predominantly by olive groves and citrus orchards. The town is located in a geo-climatic region very suitable for the use of photovoltaic technology and also presents a high risk of abandonment of agricultural lands.

The town's demand for electric energy was estimated on the basis of statistical data (source: ISTAT—Business Census, ATECO 2007). The annual quantity of equivalent electric energy employed in the economic and residential sectors of the town amounts to 44,454,428 kWh. The annual energy demand by the municipal administration was quantified on the basis of the values identified in 2011, indicated as typical ones by the local competent office. The consumption of electric energy, natural gas and diesel fuel in the municipal nursery, schools and town halls was estimated from data on energy costs and converted in kWh (conversion factors by UNI 10389). The annual energy consumption of the municipal administration summed up to 1,321,954 kWh. The total electricity needs of the entire municipality amount to 45,776,382 kWh.

At present, the town is equipped with photovoltaic systems for 1,820.55 kW rated power (source: GSE-Atlasole, 31 July 2013). The average annual electric energy they produce is estimated conservatively in 2,520,000 kWh. Considering that the annual global radiation on the horizontal surface in the local area is equal to the conservative value of 1,630 kWh/m<sup>2</sup> (source: ENEA-Atlante italiano della radiazione solare) and typical values of the efficiency of photovoltaic modules (12.5%) and BOS (85%), the energy produced by a 1 kW plant is about 1,385.5 kWh/kW. Therefore a total capacity of about 33,040 kW must be installed. These facilities cover about 65 ha, which could be reduced considering the contribution of PV plants already installed in the town.

The analysis of the local land (Sect. 4.2) was designed to verify the presence of sufficient areas that meet the prearranged technical and ambient context criteria.

#### ***4.2 Identification of Suitable Areas for Photovoltaic Systems and Quantification of Some Technical Factors Through the GIS Tool***

A study of the territory of Motta Sant'Anastasia, aimed at identifying potential suitable areas for installing photovoltaic systems on the ground, was made using the GIS tool. It employed spatial analysis (Burrough 1986) that considered: abiotic and biotic components of the landscape; historical, artistic and cultural heritage; protected and agricultural areas; hydro-geological bonds; and impacts on productive agricultural activity and on the landscape. These territorial components are contained in the GIS geo-database both in vector format and in raster format, geo-referenced in the system of Gauss-Boaga EST zone with map projection Monte Mario Italy 2 (according to the census of the European Petroleum Survey Group) for processing with the GIS tools.

The Department of Energy of the Sicily Region prepared maps of suitable and not suitable areas for the construction and operation of renewable energy plants throughout the region, in accordance with the Ministerial Decree on September 10, 2010 (<http://www.arcgis.com/home/search.html?q=owner%3AosservatorioEnergia&focus=all>). The overlap of these areas with data from the Landscape Plan of Catania approved by the Superintendence for Cultural Heritage, used by the GIS system proposed, showed that the not suitable areas do not accurately reflect the environmental and landscape constraints of the landscape plan, but includes the only level of constraint on the national scale. It was decided to complete the data for the bond landscape.

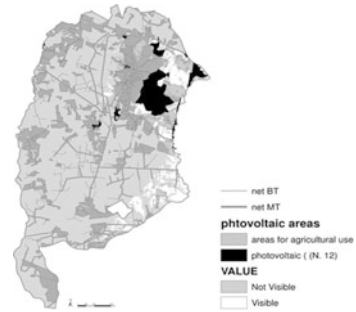
The exclusion criteria adopted in the proposed study include the areas subject to landscape bond, the areas identified in conformity with the article no. 142 of the Legislative Decree 42/2004 and subsequent amendments, the Important Bird Areas, the areas included in the Nature 2000 network (Sites of Community Importance and Special Protection Areas), the areas prone to hydro-geological constraints and their buffer zones, the built-up areas and the roads. In addition, the factors of the slope of the terrain (Slope), orientation of the ground (Aspect) and solar radiation on inclined surfaces were analyzed. They were calculated from a digital terrain model (DTM) appropriately created with a pitch of 2 m, importing the coordinates x, y, z of the land from ASCII files, the standard format used to convert the information in geo-referenced raster format. The choice of the size of the elementary cell ( $2 \times 2$  m) enables the achievement of very accurate results: the extensions of the involved surfaces can be evaluated by the values of analysis counting the differentiated cells.

In relation to land use, only lands classified as arable ones, pastures and agricultural fallow-abandoned land have been taken into account. These areas, of various sizes, are located in the municipal region with respect to the natural boundaries (roads, bridges, buffer zones of rivers etc.), and then they can be used in full for the purposes of the present work. Through the spatial analysis conducted with the GIS tool, the bounded lands and the areas that have a high degree of naturalness were excluded from the potential areas. On the basis of the ambient criteria, a first set of 204 areas was selected, with a total surface amount of 1284 ha.

As input variables, the GIS uses location (latitude, longitude), slope of the land and orientation of the land on planes oriented to the south to calculate potential total annual solar irradiance on inclined surfaces and creates a raster map with the value of irradiation measured in  $\text{MJ}/\text{cm}^2$  per annum for each cell. The average annual value of solar radiation was attributed to each area potentially suitable for the installation of photovoltaic systems. These data allow the quantification of the electric energy produced. The values of global irradiation take into account both the direct radiation and the scattered radiation, derived from the deviation of the atmosphere and the presence of clouds. The tools used in GIS were developed by the Department of Botany and Plant Pathology (Oregon State University). They are based on a trigonometric regression to improve the interpolation of the calculated results (McCune 2007).



**Fig. 1** Final suitable areas for the installation of photovoltaic systems and their inter-visibility



The distances of potential zones from the low (BT) and medium-voltage (MT) cabs of transformation were measured through the use of spatial aggregation, with the aim to quantify the cost of connection of plants to the electric network.

The yearly solar radiation on land parcels and their distances from the electrical infrastructure were used as the criteria for ranking the initial set of 204 areas, through the sub-model described in Sect. 4.3. Table 2 shows that the first 12 areas of the ranking would suffice to produce the yearly electric energy demand of the town. According to the assessment model described in Sect. 3, these areas must also satisfy the inter-visibility verification.

The analysis of inter-visibility was then done with the GIS tool on the initial set of areas identified. According to this analysis, all the first twelve areas of the ranking comply with the esthetic requirement of the assessment model.

The final result of the just described analyses is synthesized in Fig. 1, which shows the twelve areas chosen for the installation of photovoltaic systems, in compliance with all the criteria considered, their relationship with the electrical infrastructure and their total inter-visibility.

## 5 The Sub-Model Assessing the Technical Performance of Lands

The first set of areas, suitable with respect to the ambient-context constraints, were classified on the basis of their technical quality, assessed by a multi-criteria analysis using the additive model in the functional form of the weighted sum. Table 1 shows the range of values measuring the technical marginal performance of the areas and the weights assigned to the criteria.

The suitable areas with the better technical profiles were finally subjected to the verification of inter-visibility, which showed an almost homogeneous visual performance of the identified areas. An extract of the final outcome of technical assessments on the initial chosen areas is shown in Table 2.

**Table 1** Weights on technical criteria and measuring range of performance values

Technical criteria	Values	Weights
Yearly solar radiation on the surface at optimal inclination and orientation	[0; 5]	0.8
Distance from the electrical infrastructure	[0; 5]	0.2

## 6 Financial Analysis and CO<sub>2</sub> Balance of the Project

The following financial pre-feasibility analysis provides a first response on the financial aspects of the project.

The type of PV system is on the ground, grid connected, with polycrystalline silicon PV modules and fixed panels. The produced electricity is sold to the Energy Services Operator (GSE) by the “dedicated withdrawal” mode. It was assumed that the construction of the work requires one year, while the time horizon of the project was set at 20 years. After this period, the facilities will be decommissioned and disposed of, because of commercial and technological obsolescence. Therefore, the analysis assumes that the residual value of the plants is equal to zero.

For the calculation of revenues, expenses, project profit and loss accounts, cash flows and profitability indicators of the investment, a separate spreadsheet was implemented.

The revenues generated by the investment depend on the selling of produced energy. The annual net compensation amounts to € 5,152,546.61, pursuant to the AEEG Resolution no. 348/07. The investment costs include: turnkey cost of photovoltaic systems; cost of connection to the grid; regional authorization charges; and establishment cost of the company. The initial total investment cost is € 39,511,341.22. After ten years, the cost of extraordinary maintenance will be supported.

Annual operating expenses are: maintenance costs; operating expenses; financial costs, which depend on the mix between equity and borrowed capital; taxes; rent of lands.

In the event of recourse to borrowed capital, the depreciation schedule uses constant annual installments, and the applied rate of interest is the current one for investments involving the municipalities (7.14%). The discount rate is determined on the basis of the opportunity cost criterion (the current rate of return of long-term Italian Treasury Bonds, 4.5%). The inputs and outputs are expressed in current values. Table 3 shows the major indicators of financial performance for various mixes of risk capital (RC) and debt.

The realization of the project would avoid the emission of 437 gCO<sub>2</sub>/kWh, considering the fuel mix used in the Italian thermoelectric sector (ISPRA—Istituto Superiore per la Protezione e la Ricerca Ambientale 2011), while the photovoltaic technology generates the emission of 40 gCO<sub>2</sub>/kWh in its life cycle (Alsema EA de Wild-Scholten 2006). The energy self-sufficiency of the town analyzed would result in a reduction of about 18,310 tons/year of CO<sub>2</sub> emission.

**Table 2** Extract from the table on technical data and performance of the selected areas

Ranking order	Code	Distance from MT cab (m)	Yearly solar radiation (kWh/m <sup>2</sup> )	Technical performance			Project power (kWp)	Production (MWh)	Occupied area (Ha)
				On distance	On radiation	Total			
1	180	0.00	2,191.94	5.00	4.93	4.94	655.04	1,220.44	1.31
...	...	...	...	...	...	...	...	...	...
12	60	146.99	2,165.56	4.76	4.84	4.83	5,898.12	10,856.81	11.80
	Sum						30,228.74	56,039.62	60.46

**Table 3** Values of financial indicators for different financing structures

Indicators		Financing structures				
		100% RC	65% RC	60% RC	30% RC	10% RC
NPV (€/1000)	post-tax	3,083.28	2,470.66	2,295.85	1,009.50	53.9
	before tax	15,740.58	13,952.42	13,696.97	12,164.26	11,142.45
IRR (%)	post-tax	5.51	5.54	5.50	5.08	4.53
	before tax	8.88	9.36	9.45	10.23	11.21
DPBP (years)	post-tax	18–19	18–19	19–20	19–20	>20
	before tax	13–14	13–14	13–14	13–14	13–14

## 7 Concluding Discussion of Results

The Encyclical Letter *Laudato Si* suggests taking up an “ecological conversion” (Francesco 2015, Chap. VI, Sect. III) able to steer the construction of a “common house” in which fairness among living and future peoples is achieved. The integrated assessment model here proposed fits into this vision of the world, helping the investigation of technical and financial pre-feasibility of projects for energy valorization of local lands through the use of photovoltaic technology (Borrelli and Citterio 2016).

The application of the model to an actual case ascertained that it is possible for the town to realize its energy self-sufficiency by renewable sources, observing the environmental, technical and esthetical constraints, and attaining a significant reduction of impact on climate.

The model seems suitable to assist: 1. the design of analogous interventions of energy sustainability, through the analysis of geo-referenced data for the knowledge of the territory and the verification of the technical feasibility of the project; and 2. the negotiation phase of project financing by the financial feasibility analysis.

In the case study, the pre-feasibility study highlights the need for careful financial planning. In order to cover the financial requirements generated by the large tangible assets, it is necessary to identify the most appropriate sources of funding that can be activated (equity capital, senior debt, leasing etc.). Whatever the type of involved financial source is, it would be convenient if local public administrations were both promoter and guarantor of this kind of projects. Although the proposed scenario of costs reduction (International Energy Agency 2015) will eventually favor the self-production of energy from renewable sources, the adoption of special fiscal and/or financial strategies should be put in place to favor the return on investment.

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