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Economic Analysis, Innovative Educational Models and Pragmatic Sustainability: The Case Study of a Photovoltaic System on a Public Building

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ABSTRACT

The development of renewable energy has changed the utility sector, leading to a change in the interests of companies operating in the sector. The prosumer is a new emerging figure that can enable citizens and businesses to be an integral part of this change. In this context public administrations can play a key role and this study aims to assess the profitability of a photovoltaic (PV) system located in a public building (secondary school) in Italy. This analysis is integrated within an innovative teaching model that aims to stimulate the problem-solving competence of university students. The results show that the implementation of the PV system is characterised by important economic results with profits ranging from 2866 to 5670 €/kW in a 97 kW plant and from 2065 to 4012 €/kW in a 168 kW plant with a fundamental role played by the percentage of self-consumption and the avoided cost in the bill. The emission reduction in the 1st-year ranges from 56.6 to 98 tCO_2eq. Pragmatic sustainability can support the decarbonisation of our energy system by involving young people in the choices and favouring social models that reward their skills.

Keywords: Economic Analysis, Education Model, Photovoltaic, Prosumer, Public Building, Sustainability
JEL Classifications: O44, Q20, Q40, Q57

1. INTRODUCTION

Shifting from fossil to renewable sources aims to reduce environmental impacts and promote sustainable development (Saqib et al., 2024). Policies that reduce the use of non-clean energy sources are needed (Abbasi et al., 2024) to promote the spread of renewable ones (Zhang et al., 2024) through public investment (Vergil et al., 2025). It has been shown how renewable energy consumption impacts economic growth (Nosheen et al., 2024) and how the development of industrial systems is essential to increase the competitiveness of companies (Shuai et al., 2022), to combat resource scarcity (Cavallaro et al., 2023) by identifying solutions that favour circular models and energy independence (D'Adamo et al., 2023).

The growth of photovoltaics (PV) has been very significant globally and policy instruments have facilitated its deployment (Joshi et al., 2025). The role of the prosumer is considered crucial in fostering the transition to clean sources (Ceglia et al., 2022; López et al., 2024). PV systems can be studied in various applications (Leewiraphan et al., 2024) favouring the microgrid to supply necessarily clean electricity to individual homes (Attia, 2021). In this context, it is important to study its location (De Luis-Ruiz et al., 2024). Public buildings are called upon to make their contribution (Pinto et al., 2024).

Some studies focus on the contribution of primary and secondary schools (Wang et al., 2024; Xu et al., 2021) others on universities (Asante et al., 2024; Teah et al., 2019). In this respect, universities aim to support the achievement of the Sustainable Development Goals (SDGs) (Serafini et al., 2022). Living lab models that put stakeholders at the centre of their agenda are a path to follow (Purcell et al., 2019), where students propose solutions and strategies based on interdisciplinary knowledge (Mokski et al., 2023). Changes have indeed determined how even disciplines, such as engineering, must link technical solutions to social aspects (McAlexander et al., 2022). The aim should be to foster sustainable communities in which greater synergy is fostered between teacher and student, young people are given confidence and asked to have tangible results from the implementation of projects that also include the energy sector (Biancardi et al., 2023).

Similar initiatives take place in secondary schools where low-cost experiments can be used to explain the energy transformation (García-Ferrero et al., 2021), but at the same time teaching should be enriched by providing information on these aspects (Hoque et al., 2022) and the correct teaching approach should be identified to help form the correct skills (Olsson et al., 2022). Students show mixed emotions about the future where negative scenarios are considered more likely than positive ones (Finnegan, 2023), other analyses show that there is sufficient knowledge and information but nevertheless the behaviour does not follow the way of thinking (Agirreazkuenaga and Martinez, 2021). A review of the literature on the topic shows that critical thinking, systems thinking and action competence are considered crucial in preparing secondary school students to face the challenges of sustainability (Sposab and Rieckmann, 2024). Other analyses show that students' sustainable actions are positively influenced by their school experiences (Torsdottir et al., 2024).

Project-based learning implemented as part of interdisciplinary collaborations involving different stakeholders is considered preparatory to sustainable development (Podgórska and Zdonek, 2024), paying attention to student involvement (Uzorka et al., 2024) applying a pragmatic approach (Biancardi et al., 2023). This paper aims to fill this gap in the literature. It starts with an innovative teaching approach, in which management engineering students are tasked with analysing a case study of their choice by providing quantitative evaluations from a problem-solving perspective. The approach involves the development of skills through classic lectures, the presence of experts in seminars and weekly receptions to monitor progress. The case study analysed in this work also involves collaboration with other public bodies (Province of Latina and Liceo Scientifico G.B. Grassi located in Latina). The objective of this study is to evaluate the profitability of a PV system in a public building considering two different sizes of systems and two specific market contexts. The analysis will be conducted by varying some critical parameters such as the investment cost of the PV, the purchase price of energy, the sale price of energy, the percentage of self-consumption and by applying policy instruments such as the grant.

2. CASE STUDY

The Liceo Scientifico G.B. Grassi high school in the city of Latina has distinguished itself in the Pontine area for its focus on environmental sustainability issues to the point of being awarded the prestigious green flag and international eco-school certification.

2.1. Plant Location and Solar Data

The school has approximately 1400 students and approximately 100 teachers and administrative, technical and auxiliary staff. Defining the direction of the sun's rays with respect to the surface of the PV module, the azimuth angle is 0° (the panel faces south) while the tilt angle is 30° (representing the panel's inclination with respect to the horizontal plane). The average annual air temperature

Table 1: Monthly average hourly direct irradiation (kWh/m^2)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0:00												
1:00												
02:00												
03:00												
04:00												
05:00					0.010	0.026	0.022					
06:00				0.027	0.084	0.097	0.105	0.048	0.006			
07:00		0.010	0.043	0.095	0.184	0.189	0.212	0.131	0.072	0.023		
08:00	0.020	0.074	0.118	0.183	0.299	0.294	0.334	0.232	0.162	0.096	0.032	0.014
09:00	0.064	0.155	0.203	0.277	0.415	0.399	0.455	0.337	0.261	0.185	0.088	0.053
10:00	0.111	0.233	0.283	0.361	0.515	0.488	0.558	0.429	0.351	0.270	0.146	0.097
11:00	0.147	0.290	0.340	0.418	0.583	0.548	0.628	0.491	0.414	0.330	0.188	0.130
12:00	0.160	0.310	0.360	0.439	0.607	0.570	0.653	0.514	0.437	0.352	0.204	0.143
13:00	0.147	0.290	0.340	0.418	0.583	0.548	0.628	0.491	0.414	0.330	0.188	0.130
14:00	0.111	0.233	0.283	0.361	0.515	0.488	0.558	0.429	0.351	0.270	0.146	0.097
15:00	0.064	0.155	0.203	0.277	0.415	0.399	0.455	0.337	0.261	0.185	0.088	0.053
16:00	0.020	0.074	0.118	0.183	0.299	0.294	0.334	0.232	0.162	0.096	0.032	0.014
17:00		0.010	0.043	0.095	0.184	0.189	0.212	0.131	0.072	0.023		
18:00				0.027	0.084	0.097	0.105	0.048	0.006			
19:00					0.010	0.026	0.022					
20:00												
21:00												
22:00												
23:00												

Figure 1: Aerial view of the school

Figure 2: (a) 97 kW plant (b) 168 kW plant

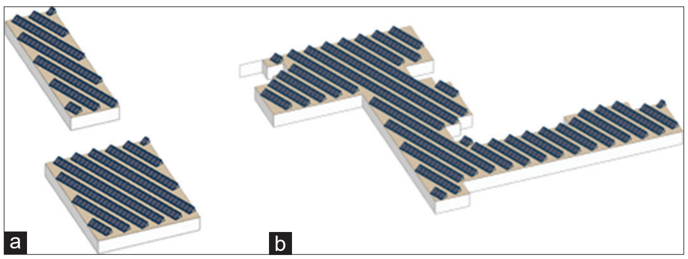
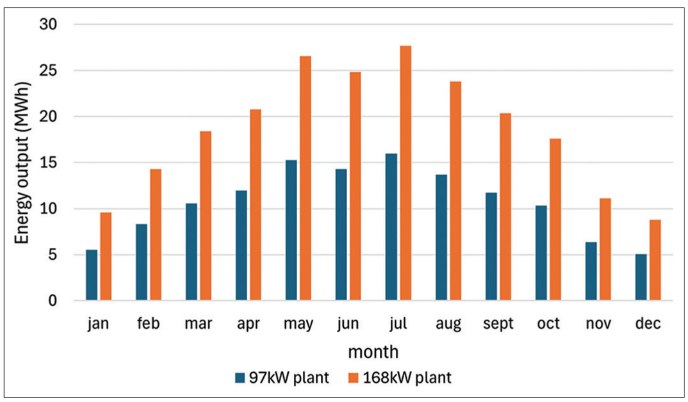


Figure 3: Energy produced by the 97 kW plant and 168 kW plant



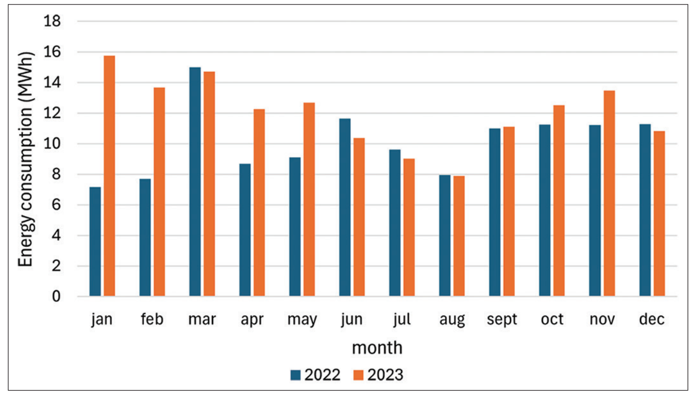
at Latina is 17.5°C, while as far as solar data is concerned, we can report the monthly average hourly direct irradiation (Table 1).

Solarius software was used to calculate the output of the PV system. The system was placed on the flat roof surfaces (with the exception of the stairwell roof), leaving out the roof of the gymnasium because it was too uneven and the single-storey part of the building due to shading from the surrounding part of the structure (Figure 1). The total area of the selected roof surface is approximately 1280 m^2. As the installation surface is perfectly flat, the PV panels will be supported by steel structures that will allow them to be tilted correctly.

2.2. Plant Dimensioning

The design choices led to two different sizes of the system to be installed (Figure 2): The 97 kW plant produces 129,167 kWh/year and the 168 kW plant produces 223,871 kWh/year. The smaller plant is located on the roof of the school's new wing and auditorium, while the larger plant is located above the main body of the high school. Plant 1 consists of 238 panels and 16 inverters while Plant 2 consists of 416 panels and 32 inverters. The panels used are monocrystalline panels characterised by high conversion efficiency and good durability and tend to perform well in variable light conditions (Atia et al., 2023; Cabrera-Escobar et al., 2024).

Figure 4: Monthly electricity consumption in the years 2022 and 2023



2.3. Energy Production

The total energy output, expressed as a monthly average, for both plants is shown in Figure 3.

The months from May to August are those with the most hours of sunshine and, consequently, the production of energy is highest. On the other hand, these same months are those in which the school's energy consumption is lowest (between July and August the school is almost always closed); to avoid wasting this energy produced but not usable by anyone, the sale of the surplus energy, which will be fed into the public electricity grid, will be a fundamental part of the economic model.

2.4. Energy Consumption

The school's energy consumption (Figure 4) was derived from electricity bill data for the years 2022-2023 and amounted to 122,965 kWh/year and 144,299 kWh/year, respectively. Since the values of the electricity expenditure for the 2-year period considered were influenced by the COVID-19 pandemic and the consequent partial or total closure of the public buildings, the school was not attended at full capacity and, therefore, it was deemed appropriate to average the energy consumption of 2022 and 2023 month by month, in order to cushion the distortion of the values due to the aforementioned situation.

To be noted is the fact that, as far as public buildings are concerned, electricity consumption is highest during the hours of maximum irradiation, i.e. when electricity production is most concentrated, so it was decided not to consider the installation of an accumulator, the economic feasibility of which would require a significant increase in the percentage of self-consumption (Ciambellini et al., 2025; Gómez-Restrepo et al., 2024). As previously mentioned, comparing Figures 3 and 4, especially in the summer months there is a surplus of energy produced in relation to the school's needs and, therefore, the possibility of feeding it into the public grid. The opportunity to sell a portion of the energy produced is certainly considerable in the case of the 168 kW plant, whose self-consumption is 57%, but not negligible in the case of the 97 kW plant, whose self-consumption is 82%.

$$NPV = \sum_{t=0}^{N}(I_t - O_t)/(1+r)^t = DCI - DCO \quad (1)$$

$$PI = NPV/I_0 \quad (2)$$

$$\sum_{t=0}^{DPBT}(I_t - O_t)/(1+r)^t = 0 \quad (3)$$

$$\sum_{t=0}^{N}(I_t - O_t)/(1+IRR)^t = 0 \quad (4)$$

$$DCI = \sum_{t=1}^{N}(\omega_{self,c} \times E_{Out,t} \times p_t^c + (1-\omega_{self,c}) \times E_{Out,t} \times p_t^s)/(1+r)^t \quad (5)$$

$$p_{t+1}^c = p_t^c \times (1 + inf_{el}) \quad (6)$$

$$p_{t+1}^s = p_t^s \times (1 + inf_{el}) \quad (7)$$

$$DCO = \sum_{t=0}^{N_{debt}-1}(C_{inv}/N_{debt} + (C_{inv} - C_{lcs,t}) \times r_d)/(1+r)^t + \sum_{t=1}^{N}(P_{Cm} \times C_{inv} \times (1+inf) + P_{Cass} \times C_{inv} \times (1+inf) + SP_{el,t} \times P_{Ctax})/(1+r)^t + (P_{Ci} \times C_{inv})/(1+r)^{10} + C_{ae} \quad (8)$$

$$C_{inv} = C_{inv,\,unit} \times (1+Vat) \times S \quad (9)$$

$$E_{out,t+1} = E_{out,t} \times (1-dE_f) \quad (10)$$

3. METHODOLOGY

The method used in this paper is based on the discounted cash flow method, which allows the economic feasibility of a project to be assessed. The cash flow method is based on estimates of inputs and outputs, estimating a useful life horizon and an appropriate opportunity cost of capital. This method is widely used in the literature to evaluate PV plants (Ciambellini et al., 2025; Kijo-Kleczkowska et al., 2022; Qiu et al., 2021). For each of the two plants, a base scenario is outlined in which revenues are estimated, deriving from savings on the cost of the energy bill and from the sale of energy, and costs, deriving from the amount of capital financed (consisting of the cost of the panels, installation and inverter), interest on the capital, costs of the electrical connection, maintenance, inverter replacement at year 10, insurance and taxes. A total financing of the investment is foreseen, thus making the equity share not present.

3.1. Economic Model

The indicators used in this work are: (i) Net present value (NPV), which measures the wealth generated by a project; (ii) Profitability index (PI), which indicates the profit per euro invested; (iii) Discounted PayBack time (DPBT), which measures the time it takes for the initial cost to be recovered; and (iv) Internal rate of return (IRR), which measures the percentage return on investment (D'Adamo et al., 2021).

Nomenclature:

C_{ae}	Administrative and electrical connection cost	p^s	Electricity selling price
C_{lcs}	Loan capital share cost	P_{Cass}	Percentage of assurance cost
C_{inv}	Investment cost	P_{Ci}	Percentage of inverter cost
$C_{inv,unit}$	Unitary investment cost	P_{Cm}	Percentage of maintenance cost
DCI	Discounted cash inflow	P_{Ctax}	Percentage of taxes cost
DCO	Discounted cash outflow	r	Opportunity cost of capital
dE_f	Decreased system efficiency	r_d	Interest rate on a loan
E_{Out}	Energy output of the system	t	Period time
inf	Rate of inflation	t+1	Following year
inf_{el}	Rate of energy inflation	S	Size
N	Lifetime of a PV system	SP_{el}	Sale of energy
N_{debt}	Period of loan	$\omega_{self,c}$	Percentage of energy self-consumption
p^c	Electricity purchase price	Vat	Value added tax

3.2. Description of Scenarios and Input Date

In accordance with section 2.2, this work concerns two different plants, as in this way the link between economic and technical dimensions can also be assessed:

- 97 plant;
- 160 KW plant.

Section 2.4 identified the percentage of self-consumption for the two plants (82% in the smaller size, 57% in the larger one). This parameter is considered fundamental in economic analyses as it is able to significantly vary the profitability of a plant (D'Adamo et al., 2023; McKenna et al., 2018; Roldán Fernández et al., 2021). As for the other parameters, the literature (Barbara et al., 2024; Cerino Abdin and Noussan, 2018; Chiacchio et al., 2019; Ciambellini et al., 2025; D'Adamo et al., 2021; 2023; Talavera et al., 2019), but also the opinion of two experts working in the trade in order to have a more precise estimation of the data - Table 2. The purchase price of energy, which becomes a foregone cost after the realisation of a PV plant and thus can be considered as a cash inflow, is evaluated in two different scenarios:

- Low Market with 0.25 €/kWh;
- High Market with 0.40 €/kWh.

The cost of energy sold is set at 0.07 €/kWh, the opportunity cost of capital is set at 5%, and the useful life at 20 years. As far as the investment cost is concerned, there is an important difference between the two plants, since the 168 kW plant is a single block as opposed to the 97 kW plant. Finally, the inflation figures are increased due to the effects of the historical conjuncture in which the study was conducted.

Table 2: Input data

Variable	Value	Variable	Value
C_{ae}	1000 €	P_{Cass}	1.5%
$C_{inv,unit}$	1395-1095 €/kW	P_{Ci}	15%
dE_f	0.7%	P_{Cm}	2.5%
E_{out}	129,168-223,871 kWh/year	P_{Ctax}	40%
inf	5.9%	r	5%
inf_{el}	4.5%	r_d	3%
N	20 years	S	97-168 kW
N_{debt}	10 years	$w_{self,c}$	57-82%
p^c	0.25-0.40 €/kWh	Vat	10%

Given the absence of incentive policies in force, two alternative scenarios to the basic one have been assumed. These scenarios involve non-repayable incentives at 20% and 40% of the total investment cost (cost of panels, inverter and installation respectively.

4. RESULTS

The objective of this work is to assess the cost-effectiveness of a PV project for a public building (specifically a school) and four separate case studies are considered, obtained from the combination of two different market scenarios and two different plant sizes.

4.1. Base Scenario

The analysis of cash flows shows that in High Market conditions already from year 1 revenues exceed costs, whereas in Low Market conditions this phenomenon occurs from year 3 - Figures 5 and 6.

The economic results obtained from the basic analysis showed the profitability of the investment in the different case studies:

- In the 97 kW Low Market case we obtained the NPV of 278 k€, the PI of 2.77, the IRR of 43% and the DPBT of 4 years and 10 months;
- In the 97 kW High Market case, on the other hand, the NPV was 550 k€, the PI was 4.47, the IRR was 110% and the DPBT was 2 years;

Figure 5: 97 kW plant in the two market scenarios

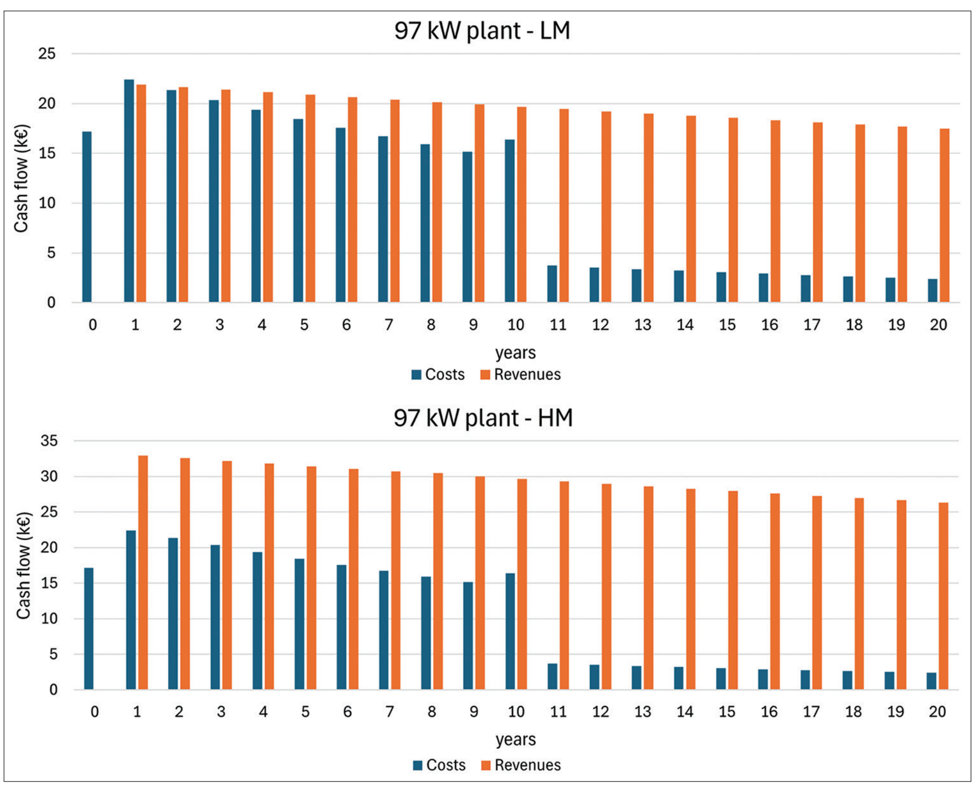


Figure 6: 168 kW plant in the two market scenarios

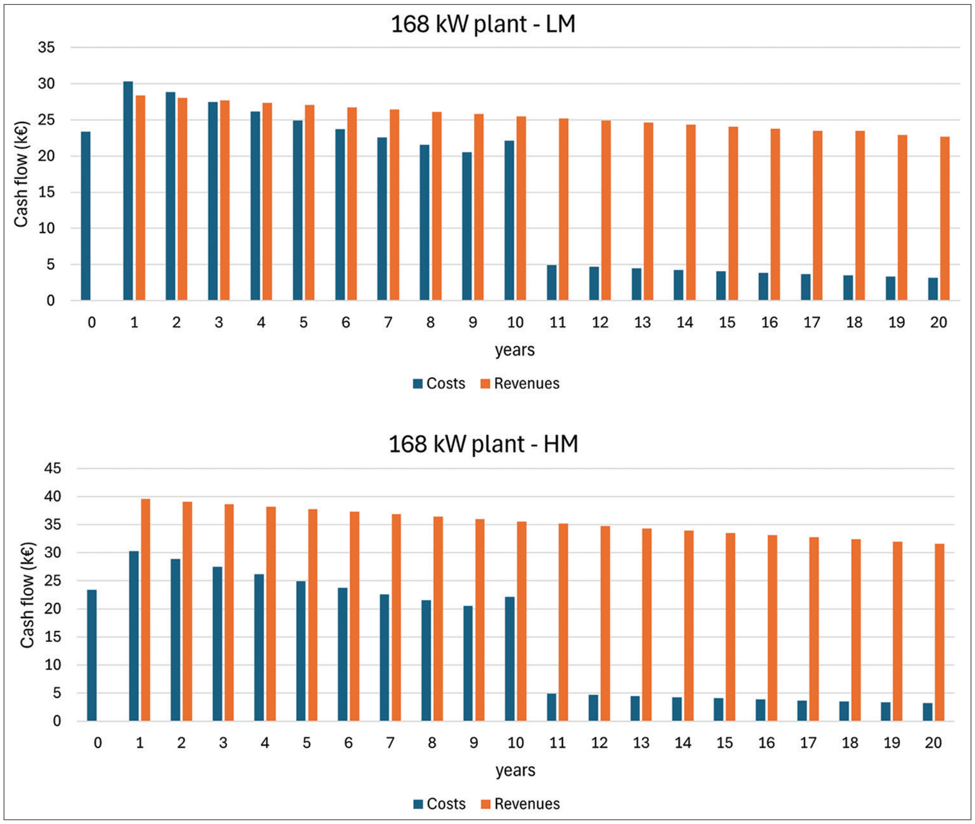


Table 3: Literature review - economic indicators

Index	Value	Country	Reference
NPV	2,158,264 R$	Brazil	(De Souza Silva et al., 2022)
NPV	7446 $	Mexico	(Hernandez-Escobedo et al., 2020)
NPV	121,134 $	Portugal	(Karanam and Chang, 2023)
NPV	9100-22,000 $	New Zealand	(Emmanuel et al., 2017)
NPV	158-315 k€	Italy	(D'Adamo et al., 2021)
DPBT	5-6 years	Italy	(D'Adamo et al., 2021)
PI	0.83-0.97	Italy	(D'Adamo et al., 2021)
NPV	31,019-232,644 €	Spain	(Talavera et al., 2011)
DPBT	16-17 years	Spain	(Talavera et al., 2011)
PBT	3 years	Jordan	(Ayadi et al., 2018)
NPV	81,996 $	England	(Lee et al., 2016)
PI	1.28	England	(Lee et al., 2016)
PBT	11 years	England	(Lee et al., 2016)
IRR	10.7-34%	United States	(Paudel and Sarper, 2013)
IRR	18.5%	Italy	(Mazzeo et al., 2015)
PBT	5 years	Italy	(Mazzeo et al., 2015)
NPV	(−400)−32 kPLN	Poland	(Kurz et al., 2023)
IRR	23%	China	(Wang et al., 2024)
PI	1.8	China	(Wang et al., 2024)
PI	1.30-2.98	Bangladesh	(Ahsan Kabir et al., 2024)
NPV	3.09-3891.15 kUSD	Bangladesh	(Ahsan Kabir et al., 2024)
NPV	15.15 MGHS	Ghana	(Asante et al., 2024)
DPBT	8 years	Ghana	(Asante et al., 2024)

- In the 168 kW Low Market case the NPV is 347 k€, the PI is 2.07, the IRR is 45% and the DPBT is 4 years and 6 months;
- In the 168 kW High Market case, the NPV is 674 k€, the PI is 4.03, the IRR is 104% and the DPBT is 2 years.

The comparison between size and market allows for different evaluations. In fact, it can be seen that the larger plant, despite the lower investment cost, is less attractive due to the lower percentage of self-consumption. This result is amplified by a sale price of the energy produced and self-consumed that is not comparable with the avoided cost in the bill. In fact, although the NPV is higher in absolute terms, the PI clearly indicates a different result where it is >0.70 and 0.44 in the Low and High Market contexts, respectively. Similarly, the NPV/Size ratio shows a value of 2065 €/kW for a 168 kW Low Market plant that becomes 4012 €/kW in the High Market context; while the 97 kW plant is 2866 €/kW in the Low Market context and 5670 €/kW in the High Market context. An expected fact is that in a context of rising energy purchase prices, the user who installs a PV system tends to increase its benefits, since the greater the savings it will acquire. There is an almost twofold increase in NPV: 272 k€ in the 97 kW plant and 327 k€ in the 168 kW plant. The differences in terms of IRR and DPBT are minimal when comparing the two plant sizes. In general, there is a very short payback time on the investment, which in the High Market context is even 2 years, and a rate of return on investment of over 100%.

In order to provide a comprehensive overview, the results obtained can be compared with what has been proposed in the literature (Table 3).

Figure 7: Sensitivity analysis - percentage of self-consumption

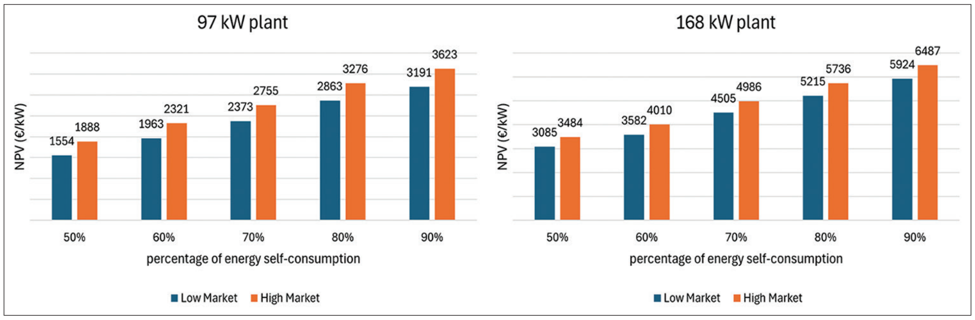


Figure 8: Sensitivity analysis - energy purchase price

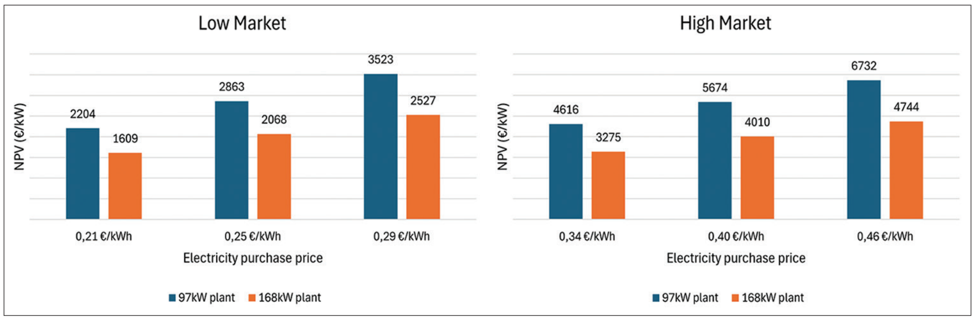


Figure 9: Sensitivity analysis - energy selling price

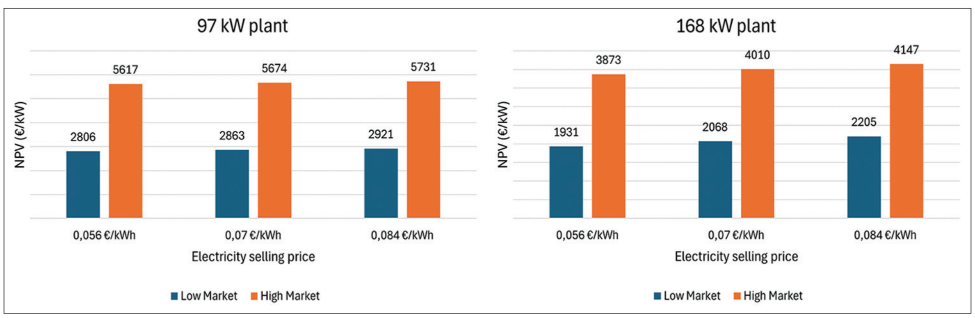
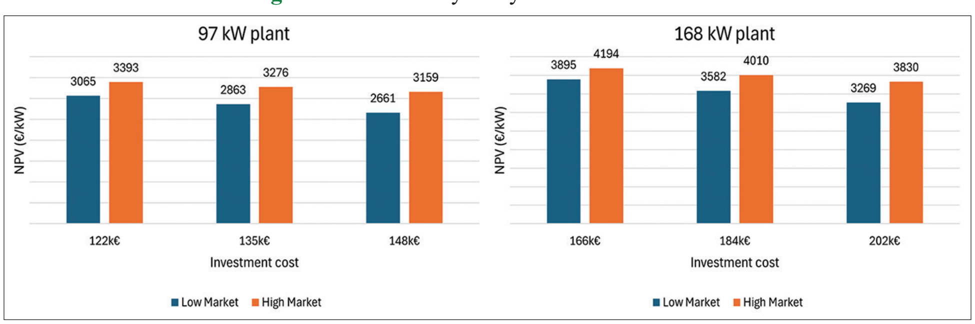


Figure 10: Sensitivity analysis - investment costs



4.2 Alternative Scenarios

4.2.1. Sensitivity analysis

Sensitivity analyses involve the variation of a single variable. In this respect, the NPV is taken as the reference indicator. Critical variables are chosen in accordance with the literature (Barbara et al., 2024; Ciambellini et al., 2025; D'Adamo et al., 2023):

- The percentage of self-consumption, which plays a key role, cannot be defined as to whether it will remain stable in the long term, so it was made to vary by 10% within the 50-90% range (Figure 7).
- Purchase price, which in the case of both High Market and Low Market was made to vary in a pessimistic scenario and in an optimistic scenario with a variation of 15% (Figure 8).
- Sales price, which was increased by 20% in the optimistic case and decreased by the same percentage in the pessimistic case (Figure 9).
- Investment cost, which represents the main cash outflow, and was varied by −10% and +10% to account for both positive and negative alternative situations to the base case (Figure 10).

It can be seen, for example, that the purchase price of energy varies from 0.40 to 0.46 €/kWh and from 0.25 to 0.29 €/kWh; while the sale price of energy varies from 0.07 to 0.084 €/kWh.

The first fact that emerges is that profitability is guaranteed in all the cases analysed. On the basis of the results obtained in both plants, it can be seen that, with regard to the first critical variable, starting with 50% self-consumption and increasing its value by 10% up to 90%, the NPV approximately doubles its value. With reference to the starting percentage, the NPV increases by 330-350 €/kW from 80% to 90% with the 97 kW plant and by 500-525 €/kW from 50% to 60% with the 168 kW plant. With regard to the second critical variable, in the 97 kW plant, with the 15% increase in the purchase price of energy, we have an increase in NPV of 600 €/kW in the LM case, while in the HM case we have an increase in NPV of around 1060 €/kW. In the 168 kW plant, on the other hand, with a 15% increase in the variable, we have an increase of 460 €/kW in the LM case and 735 €/kW in the HM case. With regard to the third critical variable, i.e. the selling price of energy, with a 20% increase we have an increase in NPV of 57 €/kW in the LM case and 34 €/kW in the HM case in the smaller plant; in the second plant, on the other hand, with the same percentage increase we have an increase of 136 €/kW in the LM case and 137 €/kW in the HM case. Finally, with regard to investment costs, i.e. the fourth and last critical variable examined, their 10% increase leads to a decrease for the NPV of 202€/kW in both the LM and HM cases in the 97 kW plant. In the 168 kW plant, on the other hand, with the same percentage increase we have a decrease in NPV of in both the LM and HM cases. Furthermore, since the objective of the alternative scenarios is also to evaluate different contexts, we proceed to consider case studies in which a non-refundable incentive is applied. The purpose of this instrument is to reduce cash outflows and their impact during the financing period, thereby reducing the debt incurred. Two alternative frameworks were assumed, with either a 20% or 40% non-refundable incentive. The results indicate for the 97 kW plant an increase in NPV of 402-408 €/kW in the two market scenarios; in the 168 kW plant, on the other hand, we have an increase of 359-364 €/kW with the 20% non-refundable incentive. In contrast, when the NPV is 40%, we have 806-812 €/kW and 721-726 €/kW in the two 97 kW and 168 kW plants (Figure 11).

4.2.2 Scenario analysis

A further step in the alternative scenarios is to vary several variables simultaneously. In this regard, revenue and cost items are separated. Also in this analysis, both an optimistic and pessimistic perspective is analysed. Analyses were conducted for both plant sizes, for the two market contexts and for an additional value of

Figure 11: Sensitivity analysis - 20% and 40% non-returnable funds

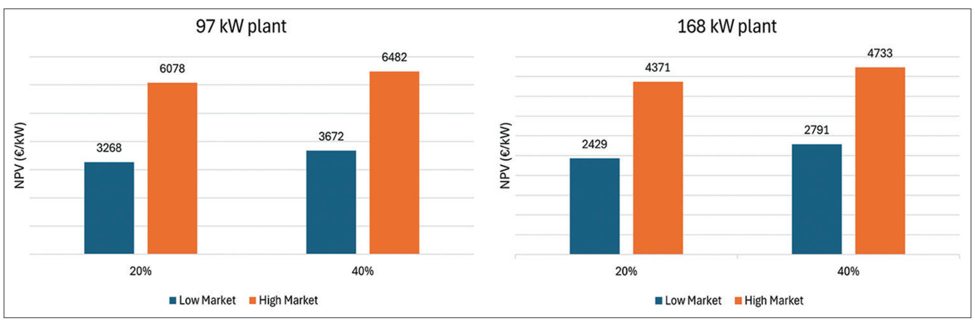
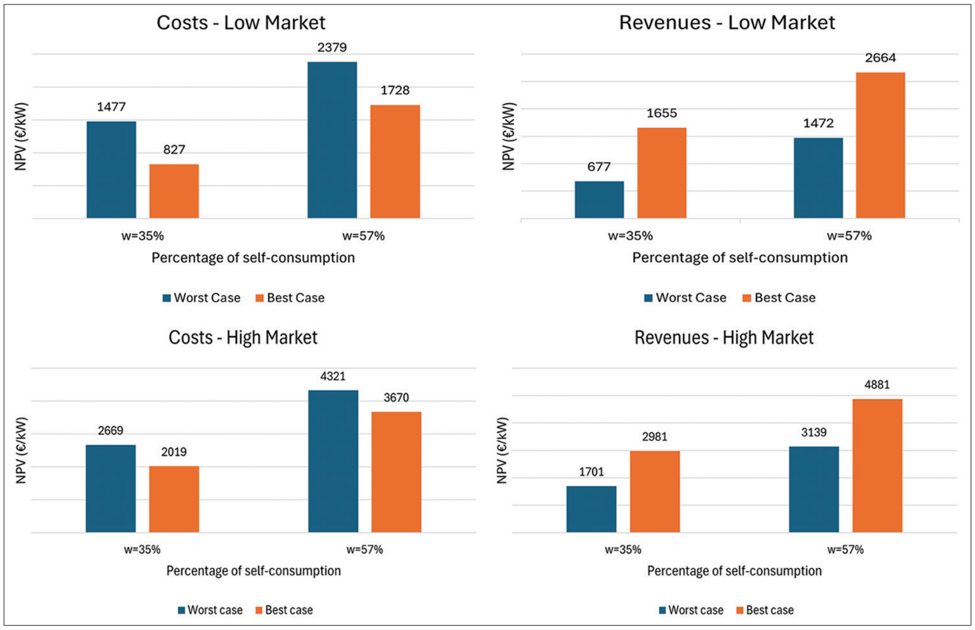


Figure 12: Scenario analysis - 97 kW plant

Figure 13: Scenario analysis - 168 kW plant

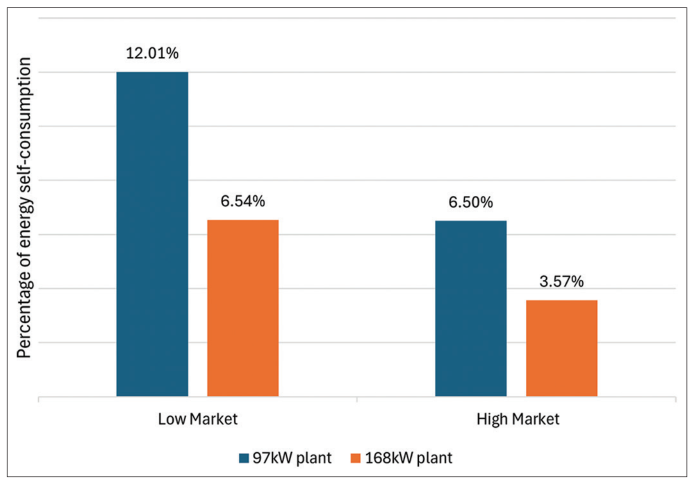


the self-consumption percentage. A decrease of approximately 20% was considered: For the 97 kW plant over 82% is valued at 60% and for the 168 kW plant over 57% is valued at 35%. On the revenue side, the purchase price of energy (±15%) and the sale price of energy (±20%) were considered. On the cost side, changes in maintenance costs (±5%), insurance (±5%) and inverters (±10%) are considered. The purpose of such a detailed analysis is to represent a large number of situations that might occur in the future - Figures 12 and 13.

Considering the 97 kW plant in the LM case with 82% self-consumption percentage and analysing from the revenue side, the NPV values are 2146 €/kW in the pessimistic case and 3581 €/kW in the optimistic case, respectively; in the HM case, they are 4559 €/kW and 6789 €/kW, respectively. On the cost side in the LM case, the NPV values are 3168 €/kW and 2536 €/kW, respectively; in the HM case, the NPV values are 5979 €/kW and 5346 €/kW, respectively. Repeating the analysis for self-consumption 60%, on the revenue side, there is a reduction ranging from 790 to 1010 €/kW in the LM case and from 1440 to 1870 €/kW in the HM case; on the cost side, 900 €/kW and 1600 €/kW in the LM and HM contexts, respectively.

Considering, on the other hand, the 168 kW plant in the LM case with 57% self-consumption percentage and varying the parameters on the revenue side, the NPV values are 1472 €/kW in the pessimistic scenario and 2664 €/kW in the optimistic one; in the HM case, 3139 €/kW in the pessimistic scenario and 4881 €/kW in the optimistic one. On the cost side in the LM case, NPV is 2379 €/kW in the optimistic scenario and 1728 €/kW in the pessimistic one; in the HM case, NPV is 4321 €/kW in the optimistic scenario and 3670 €/kW in the pessimistic one. Assuming self-consumption at 35%, similar assessments emerge as those already proposed for the other dimension.

Figure 14: Break-even point analysis as a function of self-consumption percentage



The analysis of the different case studies confirms the profitability of these plants and shows important variations to be evaluated. However, they are not assigned probabilities of occurrence to events but allow decision-makers to have snapshots in certain contexts.

4.2.3 Break-even point analysis

The break-even point analysis identifies the point at which the revenues from renewable energy production equal the total investment costs, i.e. when the NPV becomes zero. The critical variable chosen for this analysis is the percentage of self-consumption (Figure 14).

The results show that the percentage of self-consumption that cancels the NPV is 12% in the Low Market case and 6.5% in the High Market case for the 97 kW plant. In contrast, it is 6.5% in the Low Market case and 3.6% in the High Market case for the 168 kW plant.

4.2.4 Risk analysis

Finally, the risk analysis is proposed to carry out a simulation of the PV plant model for the simultaneous variation of several variables by assigning them a distribution function by means of a mean value and standard deviation. For this purpose, the Monte Carlo method is used to generate 1000 iterations of the NPV. The three critical variables are the investment costs, the purchase price and the selling price of energy.

For 82% self-consumption, the 97 kW plant in the LM case has a 52.4% probability that the NPV values are between 225 and 325 k€; while in the HM case there is a 32.1% probability that the NPV values are between 500 and 600 k€. When, on the other hand, self-consumption is different and is 60%, the NPV in 65.8% has a value between 140 and 240 k€ in the LM case and in 42.6% has a value between 340 and 440 k€ in the HM case.

Relative to the 168 kW plant, the 57% self-consumption in the LM case has a 44.7% probability of having NPV values in the range of 300-400 k€ and 28.8% in the range of 625-725 k€ in the HM case. In the context of the reduction of self-consumption to 35%, the NPV in the LM case is 56.3% likely to have a value in the range 145-245 k€ and in the HM case 44% likely to have a value in the range 345-445 k€.

4.3 Environmental Analysis

After conducting the economic analysis, it is appropriate to conduct an environmental analysis that aims to assess the benefits of adopting a PV system compared to fossil energy production, i.e. the reduction in emissions associated with producing one kWh of energy from renewable sources compared to one kWh of energy from fossil sources (Barbara et al., 2024).

$$RE_{CD}=ECD_{(FF)}-ECD_{PV} \quad (11)$$

$$ECD_{FF}=ECD_{(OI)}\times PEM_{(OI)}+ECD_{CO}\times PEM_{CO}+ECD_{NG}\times PEM_{NG}+ECD_{GD}\times PEM_{(GD)}+ECD_{(OT)}\times PEM_{OT} \quad (12)$$

where RECD = reduction in carbon dioxide emissions; ECD = carbon dioxide emitted from specific resources; PEM = percentage in the energy mix of specific resources; FF = fossil fuels; PV = photovoltaic; OI = oil; CO = coal; NG = natural gas; GD = gas derivatives and OT = other.

Data from the literature are as follows (Bakhtyar et al., 2017; Bravi et al., 2011; D'Adamo et al., 2021; Edenhofer et al., 2012; ISPRA, 2022; Peng et al., 2013): ECD_{PV} 42 gCO_2eq/kWh, ECD_{OI} 518 gCO_2eq/kWh, ECD_{CO} 927 gCO_2eq/kWh, ECD_{NG} 372 gCO_2eq/kWh, ECD_{GD} 1382 gCO_2eq/kWh and ECD_{OT} 644 gCO_2eq/kWh. The percentage mix data are calculated based on the school's electricity bills, hence PEM_{NG} 74.34%, PEM_{CO} 14.92%, $PEM_{(OI)}$ 3.18% and PEM_{OT} 7.56%. It should be noted that according to Equation 11, it is assumed that the energy mix is composed of fossil sources, although the bills also report the renewable share as the objective is to compare energy obtained from clean versus environmentally harmful sources.

The results show that the emission level of fossil sources (ECD_{FF}) is 480 gCO_2eq/kWh and the emission reduction (RECD) is 438 gCO_2eq/kWh (obtained as the difference between 480 gCO_2eq/kWh and 42 gCO_2eq/kWh) using the PV system compared to the fossil fuel mix. The objective is not only to calculate the emission reduction in the 1st year, but also over the entire lifetime. In this respect, the plant's performance reduction of 0.70% should be highlighted (Table 2). The 97 kW plant saves 56.6 tCO_2eq during the 1st year and 49.5 tCO_2eq during the 20th year; in total, 1006.7 tCO_2eq will be saved over the plant's entire lifetime. The 168 kW plant, on the other hand, reduces its emissions by 98 tCO_2eq in the 1st year of operation and 85.8 tCO_2eq in the final year of operation; in total, emissions will be reduced by 1836 tCO_2eq.

5. CONCLUSION

The design of a PV system is preparatory to the creation of an infrastructure through which access to clean energy can be ensured not only for all those attending the school but also for the general public by feeding the surplus energy produced into the public electricity grid. This result generates a knock-on effect as it can make other schools aware of the possibility of installing this type of system to promote the use of clean energy and spread the concept of sustainability, especially among the youngest.

In the absence of incentive policies, the main economic benefit comes from cost savings on the utility bill. In this regard, it is therefore important to consider the purchase price of energy, since a higher value of energy determines a greater convenience in installing a PV system. It must be monitored that this price does not increase too much as it could lead to a phenomenon of energy poverty that could affect those who have not installed PV systems not by choice, but due to poor economic conditions. The other key variable is that related to the percentage of self-consumption, since a virtuous behaviour that synchronises consumption and demand increases the profitability of the investment. The results of this work show that the smaller sized plant tends to be more cost-effective precisely because of its ability to intercept energy demand; this fact emphasises the need for correct plant sizing.

The economic results show that for the 97 kW plant, the following values are obtained: NPV 278-550 k€, PI 2.77-4.47, IRR 43-110% and DPBT 2-5 years depending on the market context. For the 168 kW plant, the following values are obtained: NPV 347-674 k€, PI 2.07-4.03, IRR 45-104% and DPBT 2-4.5 years depending on the market context. These values highlight the cost-effectiveness of implementing this project. The environmental analyses also support the achievement of the sustainability targets: the results over the 20 years allow a reduction of 1006.7 and 1836 tCO_2eq in the two plants respectively. The attainment of SDG 7 is therefore concrete, and the role of the prosumer is crucial in achieving this goal.

The limitations of this work are related to the absence of a social analysis to assess how the student community would react to the implementation of this installation, but in general there is a need for social analysis oriented to assess perceptions and behaviour towards sustainable schools. Other limitations are related to economic analyses: In this work it does not seem to be useful to install a storage battery, but such technology is able to balance the intermittency of the solar source and could be useful in an energy community model. Similarly, such a model of social energy sharing is subject to significant subsidies, and this could push public administrations to be protagonists of the ecological transition. In this respect, the neighbourhood of the school should be evaluated and it should be understood whether the prerequisites exist.

This work also provides policy implications. Indeed, the grant could support the implementation of facilities in those public administrations that do not have much liquidity and such action does not seem to find adverse phenomena. Indeed, the role of public administration (and in particular of primary and secondary schools and universities) is to provide an example to follow. The growth of renewables, and in particular photovoltaics, is significant in recent years, but the availability of roofs identifies the need to install new plants in order to reduce dependence on fossil fuels and energy from other countries. This translates into a reduction of geopolitical risks. The availability of energy that is produced and not self-consumed may prompt public administrators to consider the conditions for establishing energy communities, also supporting poor institutions, thus favouring charitable models. Finally, the communication model is one that must involve young people, make them feel part of the change. This work, however, is limited to assessing the cost-effectiveness of a green project. Finally, it shows that the availability of end-of-life modules can lead to benefits in terms of the circular economy and the opportunity to reuse these materials in industry leads to less dependence on Asian raw materials. Recycling models for PV modules should therefore be encouraged. Finally, this work demonstrates that in the presence of a more significant inflation value, this generates an optimistic scenario in terms of profitability since this parameter has a greater impact on revenues than on operating costs in a PV plant.

The innovative education model is based on a simple principle: greater synergy between university lecturers and their students. In a fast-moving world, where artificial intelligence aims to provide answers, there is an opportunity to enhance the human skills that arise from the university context in order to bring together this dual green and digital transition. These skills undoubtedly include problem solving in order to find solutions to real problems, the ability to work in a team and the ability to relate to the outside world in order to identify missing data. Pragmatic sustainability models go far beyond a simple ideological view, as they are based on economic, environmental and social analyses that aim to actually demonstrate the benefits of green projects. This is a context in which young people can believe that their dreams can be turned into reality, in which when faced with problems it is necessary to react in order to find solutions. The challenge of sustainability cannot be met with good intentions, but with concrete actions by building sustainable communities where an altruistic vision allows human skills to be placed at the centre of a future that looks towards achieving the SDGs.

6. ACKNOWLEDGMENTS

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