A student-driven multilevel approach for increasing energy sustainability of remote areas in the Emilia Romagna Apennines

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Abstract: This paper is aimed at discussing a series of energy sustainability solutions proposed by a master class of students in environmental engineering using analytical and visual collaborative tools. The activities described are part of the class "Sustainability and renewable sources" at the University of Modena and Reggio Emilia. Six groups of 3-4 students worked on six energy efficiency and sustainability projects chosen from a remote area of the Apennines in Emilia Romagna. The specificity of the case-study framework allowed the implementation of projects where different sustainability aspects are integrated using tools of transitional thinking: agro-food production, use of renewable energy sources, waste management and social integration were considered. Each group identified the key actors for each project, allowing them to approach sustainability from a multilevel perspective. Net Present Value analyses were applied to evaluate economic viability of each project. Photovoltaic power plants and boilers fueled with local wood are the main renewable energy source identified to promote energy sustainability in each project. As result, the combination of the six works creates a powerful tool to demonstrate possible best practices for remote mountain areas.

1. Introduction

The socio-economic and environmental evolution of a country may develop differently depending on geographical differences within the national territories [1]. In example, the Italian Alps and Apennines have developed, over the years, specific policies that may be a result of historical legacies (i.e. the "Usi Civici" established since the governance of Matilda of Tuscany) or modern laws to contrast the depopulation [1]. Compared to Apennines, the Alps have received higher attention in history, ethnography and geography [2,3]. Apennines therefore require proper investigation especially from a demographic point of view. Studies on territorial marginalization in Italy have also reflected the transitional period that started from the end of the Second World War [4,5].

The common category that allows a comprehensive analysis of areas located above 600 m a.s.l. is the marginality: "the process of population loss is parallel to that of loss of economic dynamism"[6]. Demographic degradation leads to a weakening of the production system, the loss of essential public services, and a reduction in the capacity to produce income. On the other hand, the difficulty of the mountain system to support the lifestyles that emerged with the economic boom pushed the population to migrate to urban centers located on the plains. Nowadays the internal areas represent laboratories for innovative economic and environmental development from cutting edge renewable energy use to virtuous waste management systems; for the implementation of social integration projects [7,8].

Starting from this problem statement, aims of this study are the definition of a combination of solutions for increasing social and environmental sustainability in remote mountain areas, together with the didactical goal of providing a high-level experience to mechanical and environmental engineering master students through their direct involvement and empowerment in the process. This work focuses on two villages located in the Emilia Romagna Apennines: “San Martino di Polinago” under Modena province and “Cecciola” under Reggio Emilia province. The proposed multilevel approach derives from the studies of Frank W. Geels and their development in the work of the European Institute of Innovation & Technology (EIT) [9]. These case studies were then ranked as a function of urgency, possible impact and importance for the local community [9]. Six different cases were chosen and provided to six groups of master engineering students. The goal of the student's work consisted in following all the required steps to propose social and energy sustainability solutions.

The group projects lead to the detailed sizing of a heterogeneous combination of renewable energy systems, ranging from biogas production with cattle manure, to the installation of photovoltaic panels on private and public buildings. Several groups paid particular attention to the valorization of the chestnut woods maintenance as source for wood stoves and gasification systems that can work with different residual biomasses [10,11]. Gasification systems have higher efficiency respect of wood stoves but have often higher maintenance costs due to the cleaning of the gas conditioning stage [12-15] from soot and tars [16]. Results showed the successes of empowering master students in experimental and participative didactic projects with the win-win outcome of allowing a learning-by-doing experience together with demonstrating the effectiveness of blended solutions for the social and environmental sustainability of remote areas.

2. Materials and Methods

2.1. Case studies

Table 1 resumes the projects developed by the six groups of master students together with the location: Cecciola, a small village located in the mountains of Reggio Emilia; the village of Borgo Cà Rossi in the Modena Province, a farm (Azienda Agricola “Luciniera”), a cattle farm (Azienda Agricola “Rossi”), a restaurant (Parco Santa Chiara) all located in the mountains of Modena. Each case study is characterized by old residential or industrial buildings with stone walls, most of them are currently heated with fireplaces and wood stoves. The main Renewable Energy Sources (RES) currently used is chestnut wood, obtained every year from the maintenance of chestnut forests closest to the case studies. Depending on the case, wood logs, chips or pellets are used as primary fuel sources to heat the building.

Table 1. Case studies summary

Group	Location	Type of building involved	Main RES involved
A	Cecciola, Ventasso (RE)	Old houses to renovate	Wood chips combustion
B	Cecciola, Ventasso (RE)	Existing holidays houses and chestnut products shops	Pellets combustion

C	Borgo Cà rossi, San Martino di Polinago (MO)	Existing homes and holidays houses	Wood chips combustion
D	Parco Santa Chiara, Monchio di Palagano (MO)	Bar, Restaurant and park service center	Wood chips and pellets combustion, Photovoltaics (PV) power plant
E	Azienda Agricola “Luciniera”, San Martino di Polinago (MO)	Existing homes and services buildings	Wood logs combustion, Photovoltaics (PV) power plant
F	Azienda Agricola “Rossi”, San Martino di Polinago (MO)	Existing homes and services buildings	Biogas from cattle manure

2.2. *Proposed approach*

In order to give to the master students the necessary set of skills to face the case studies and the complex problems they met; an initial training was provided. The training covered technical notions on RES, and as complementary subject, students were trained on the “Multilevel Perspective” approach to social transition analysis.

First, the groups were asked to identify the stakeholders and to plot them into a modified Mendelow's Matrix [17] as the one reported in Figure 1. The most important stakeholders are those that are within the quadrant identified by greater influence and greater interest: “Key Players”. Reiterating the process varying the axis from interest to adaptation and to influence, allow the creation of a Venn diagram that collects all the key players of the various permutation of the matrix. The intersection between these circles, represents the key stakeholders. The key stakeholders are the actors to focus on, to collaborate with and discuss continuously about the project and to be involved in the decision-making process.

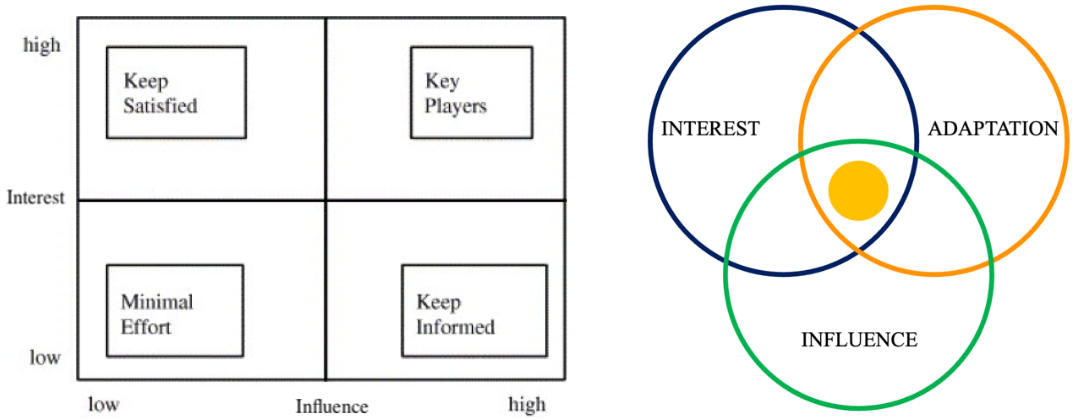

Figure 1. Influence-interest map modified from [18] on the left, Venn diagram of key actors on the right.

Once the key stakeholders were identified, the students interviewed them in order to obtain all the information necessary to know the current situation and to identify the expectations of the actors, both from a technical and a social point of view. A visual tool, the “Pentagonal Problem” [9], was used to facilitate the interview. Finally, the groups were briefly instructed on RES economics to approach the economic aspect of the projects in a competent way: initial investment planning, incentives or tax deductions, time dependent cash flows using the Net Present Value approach and return of the investment [19].

2.3. *"Group A" case study*

Group A investigated a hamlet of 5 building units. The site is owned by an endeavor called Terra delle Valli s.n.c. that administers several holidays houses, that produces and sells chestnut-based foods (produced by a farm called Agriappennino) and that manages a small chestnuts forest of about 6 hectares that produces about 40 tons of residual wood every year. The endeavor is interested in renovating the hamlet in order to refurbish guest accommodations. The renovation project has the goal to obtain 3 holiday houses, 1 service room and 1 large meeting room with a total surface area of 300 m^2. Considering a cold climate and stone walls without insulation, a precautionary specific primary energy of 250 kWh/m^2 is considered to heat the building during the winter [20]. Furthermore, a detailed calculation regarding expected host occupation was done to evaluate the heat for hot water service (about 3379 kWh/year) [21]. Finally, using a global heat generation efficiency of 65% [21] a total primary energy needs of 120538 kWh/year is estimated.

2.4. *"Group B" case study*

Group B investigated 3 holiday houses ("Il Portale", "La Volta" and "La Piagna") and 1 meeting room ("Sala Polivalente"). The site is owned by Terra delle Valli s.n.c. that uses the building "Bottega della Castagna " to sell chestnuts and chestnut-based foods. Table 2 resumes energy consumption and details about existing thermal energy generators of the listed buildings.

Table 2. Group B case study

Building	Bedrooms	Existing heat generation	Primary energy consumption
Salone Polivalente	9	LPG heat and hot water generator	6443.29 kWh/year
La Piagna	13	LPG heat and hot water generator	2577.32 kWh/year
La Volta	12	Pellet stove (heat) and electrical boiler (hot water)	2143.5 kWh/year (hot water only)
Il Portale	26	Pellet stove (heat) and electrical boiler (hot water)	5160.2 kWh/year (hot water only)

2.5. *"Group C" case study*

Group C case study is a small village of 7 buildings, 2 of them are holiday houses, placed in the mountains of Modena. The holiday houses are used for only 1 months during the winter season, while the other 5 houses are occupied all the year. LPG boilers, wood stoves and fireplaces are used as heat generators. Wood is derived from 20 hectares of public forest of chestnuts, oaks and beeches [22].

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Table 3. Group C case study

Building	Net area [m^2]	Existing heat generation	Primary energy consumption
1+2	322.8	LPG heat and hot water generator, wood stoves and fireplaces	6308.22 kWh/year
3	80	LPG heat and hot water generator, wood stoves and fireplaces	39331.4 kWh/year
4	95	LPG heat and hot water generator, wood stoves and fireplaces	46706.4 kWh/year
5	140	LPG heat and hot water generator, wood stoves and fireplaces	68829.96 kWh/year
6	85	LPG heat and hot water generator, wood stoves and fireplaces	52091.86 kWh/year
7	80	LPG heat and hot water generator, wood stoves and fireplaces	39331.4 kWh/year

2.6. "Group D" case study

Group D case study consists in a bar restaurant located in a public park ("Parco Santa Giulia"). The park has a total area of 27 hectares of chestnut and oaks forest. The facility is open daily during the summer season and it is open on the weekend during winter season. About 15000 kWh of thermal energy is produced by an LPG heat generator every year. Bar and restaurant kitchen have a not-neglectable electrical energy consumption (about 17162 kWh every year).

2.7. "Group E" case study

Group E investigated a small farm called "Luciniera" composed of 133 m^2 of buildings, a service building and a barn. The existing annual electrical energy consumption is 3722 kWh, thermal energy is provided by a 20 kW pellet stove, an electrical boiler for hot water, a wood stove and a fireplace. Wood pellet consumption is about 200 kg/year and wood logs consumption is 7 tons/year. The owner of the farm has presented to the students a project for the renovation of the farm that will include a farmhouse with 3 small apartments, a meeting room and a kitchen in the substitution of the existing barn. The project will also create a small camping area with 5 parking spots and a shared bathroom facility. The farm also comprehends a chestnut forest of about 2 hectares.

2.8. "Group F" case study

Group F investigated the cattle farm "Rossi" with a total number of 59 cows for milk production to be used in the Parmigiano Reggiano supply chain. The farm has an electrical energy consumption of 15101 kWh/year and a total wood logs consumption for heating purposes of 20 tons/years.

3. **Results**

3.1. Group A project results

The buildings object of this study cannot install photovoltaic panels due to landscape regulamentation laws [23]. The group of students found out that the key actors of the proposed project are the company Terra delle Valli Snc, a farming company Agriappennino, Cecciola tourism center and the Apennines local action group (GAL: gruppo di azione locale), a partnership of public authorities and private players that promote local development in rural areas with an integrated bottom-up approach and the commitment of various stakeholders.

Concerning the energy sustainability of the renovation project, the student group proposed a 100 kW_{th} boiler fueled with wood chips. The modeled wood chip consumption is about 30 tons per year that can be obtained from the local chestnut forest with a cost of about 800 €/year. The total investment (CAPEX) is about 75000 € considering also the purchase of a woodchipper and the fabrication of the wood storage. About 6000 €/year is the maintenance and operation cost (OPEX). This solution was compared to a standard LPG boiler equipped with an external storage tank that is characterized by a CAPEX of about 11931 € and an OPEX of 12266 €/year. The comparison Net Present Value (NPV) is reported in Figure 2a (calculated using a discount rate of 5%), here the payback time is about 14 years and the NPV at the 25 year is about 22000 €.

3.2. Group B project results

The holiday houses described in the project cannot use photovoltaic panels for electrical energy production because the village is under the landscape regulamentation [23]. The group of students found out that the key actors of the proposed project are the same as the previous "Group B". Concerning the energy sustainability of the project, two scenarios are proposed and compared to the existing solution through the NPV curves reported in Figure 2b:

- <u>Scenario 1:</u> two wood pellet boilers are used for "La Piagna" and "Salone Polivalente" houses. For the first house, a 25 kW_{th} boiler is used and, for the second house, a 31 kW_{th} boiler is used. Wood pellets is purchased at a cost of about 293.3 €/ton. For the hot water production of "La Volta" and "Il Portale" holidays houses, electrical heat pumps are proposed in the substitution of electrical boilers. "Ecobonus 65%" tax reduction [24] is considered for heat pumps investment and "Conto Termico 2.0" subsidy [25] is considered for wood boiler investment. CAPEX of this solution is 22595 €.
- <u>Scenario 2:</u> two wood pellet boilers are used for "La Piagna" and "Salone Polivalente" holidays houses. For the first house, a 25 kW_{th} boiler is used and, for the second house, a 31 kW_{th} boiler is used. Wood pellets is self-produced from chestnut forest wood using a chipper and a pelletizer. The total cost for wood pellet production is about 232.3 €/ton. The surplus of wood from the forest is sold to the market. For the hot water production of "La Volta" and "Il Portale" holidays houses, electrical heat pumps are proposed in the substitution of electrical boilers. "Ecobonus 65%" tax reduction is considered for heat pumps investment and "Conto Termico 2.0" subsidy is considered for wood boiler investment. CAPEX of this solution is 25685 €.

3.3. Group C project results

The key actors of this project are the holiday house owners and the inhabitants of the village. Also in this case study, photovoltaic plants are not allowed for landscape regulamentation. For this reason, project group C proposed a comparison between 6 wood log boilers installed in the 6 houses (Scenario 1) and a centralized thermal power production through a wood chip boiler (Scenario 2). Details about these solutions are reported below:

- Scenario 1: for the buildings 1 and 2 (holiday houses), a 20 kW_{th} wood logs boiler was proposed. For the remaining houses, 5 wood log boilers with an average nominal thermal power of 25-30 kW_{th} were suggested. A total wood log consumption of 69.15 tons/y was calculated (about 2.5 % of the total wood biomass availability from the local forest). A wood storage area of about 206 m^2 was evaluated. “Ecobonus 65%” tax reduction is considered for this investment. The total CAPEX is about 156664 € and the annual OPEX is about 2090 €/year (a wood cost of 20 €/tons is considered for wood cutting into logs).
- Scenario 2: for all the buildings, a centralized wood chips boiler with a nominal thermal power of 120 kW was proposed. A total wood chip consumption of 61.9 tons was calculated. The chips are produced by a tractor driven chipper. To manage the wood chips amount, a customized storage system of 270 m^3 was designed. The boiler will be installed in a service room, and it is connected to a water puffer of 4 m^3 of volume, providing hot water to a dedicated district heating line. CAPEX cost is about 117996 €, lower than the Scenario 1, instead OPEX cost is higher compared to Scenario 1 (5634 €/year). “Ecobonus 65%” tax reduction is also considered for this investment.

NPV analysis (Figure 2c) was done comparing the existing solution (LPG boilers and fireplaces) with the two scenarios described above. Two discount rates (5%and 10%) were simulated for the Scenario 1, only one for the Scenario 2. The first solution has a good payback time and NPV value at 15th years, it is generally more feasible than the Scenario 2 where chipping cost and high boiler maintenance cost decrease the profitability of the investment.

3.4. Group D project results

Project group D proposed a comparison between a wood pellet and a wood chips boiler to fulfill heat requirements of the bar restaurant and a photovoltaic (PV) power plant to reduce electrical energy consumption from the grid. Concerning wood boilers comparison, the following parameters are considered in the NPV comparison with existing solution (Figure 2d):

- Wood pellets boiler (32 kW of nominal thermal power): CAPEX=10000 €; OPEX = 1075 €/year (considering a pellet cost of 0.3 €/kg); “Conto Termico 2.0” subsidy.
- Wood chips boiler (32 kW of nominal thermal power): CAPEX=19500 € (12500 € boiler, 5800 € chipper; 1200 € chip storage); OPEX = 725 €/year (considering operation cost of the chipper and of the boiler); “Conto Termico 2.0” subsidy.

Various photovoltaic (PV) power plant configurations were designed and simulated. The more suitable resulted the 13.95 kWp configuration able to reduce electrical energy consumption of the building to about 60%. The PV array is composed of 37 modules of 400 Wp nominal power and a 3 MPPT 15 kWp inverter. CAPEX of the plant is about 23250 €, OPEX is neglectable and the investment can benefit from “Bonus 50%” tax reduction [26]. Furthermore, the PV energy not used by the building is injected into the national grid and it is valorized with “Scambio sul posto” feed in tariff [27]. Considering a discount rate of 5%, the calculated Payback of the FV investment is about 7 years, NPV at 25 years is 20403 € and Internal Rate of Return is 13.06%.

3.5. Group E project results

Project group E proposed two comparisons between LPG / wood logs / wood chips boilers to fulfill heat requirements of the renovated farmhouse and a photovoltaic (PV) power plant to reduce electrical energy consumption. Concerning boilers comparison, the following parameters are considered in the NPV comparison with existing solution (Figure 2e):

- Wood logs boiler (20 kW of nominal thermal power): CAPEX=4900 €; OPEX = 565 €/year (considering a wood logs cost of 0.02 €/kg)

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- Wood chips solution (20 kW of nominal thermal power): CAPEX=10700 € (8700 € boiler and auxiliaries, 1000 € chipper; 1000 € chip storage); OPEX = 740 €/year (considering a wood logs cost of 0.02 €/kg, the operation cost of the chipper and of the boiler).

Also, a photovoltaic (PV) power plant configuration was designed and simulated. The designed PV nominal power is 2.835 kWp configuration able to reduce electrical energy consumption of the building to about 50%. The PV array is composed of 9 modules of 315 Wp nominal power and a MPPT 3 kWp inverter. CAPEX of the plant is about 5613.3 €, OPEX is neglectable and the investment can benefit of "Bonus 50%" tax reduction. Furthermore, the PV energy not used by the building is injected into the national grid and it is valorized with "Scambio sul posto" feed in tariff. Considering a discount rate of 5%, the calculated Payback of the FV investment is about 12 years, NPV at 25 years is 1500 € and Internal Rate of Return is 8.46%.

3.6. Group F project results

Project group F proposed a small-scale biogas CHP plant that uses cow manure as feedstock biomass. Based on the number of cows and the total manure amount to use, the designed electrical power is about 11 kW, the total annual electricity production is about 30.7 MWh (that is two times the existing electricity consumption of the buildings) and the thermal energy available is about 78 MWh/y (more than the thermal energy requirements of the building of 48 MWh). Two biogas technologies were considered in the NPV comparison with the existing solution (Figure 2f):

- Commercial turn-key biogas CHP plant (11 kW_{el} size): in this case an extra feedstock is required to run the plant continuously [29]. In this project a daily apport of 1.6 ton/day of wasted whey from the closest "Parmigiano Reggiano" cheese production company is considered. Economical details of this solution is: CAPEX=135000 €; OPEX = 5000 €/year; DL n. 145/2018 [28] subsidy.
- D.Y.I. biogas power plant (11.25 kW_{el} size): in this case no thermal energy is available from the power plant. Economical details of this solution is: CAPEX=29000 €; OPEX = 1000 €/year; DL n. 145/2018 for subsidy.

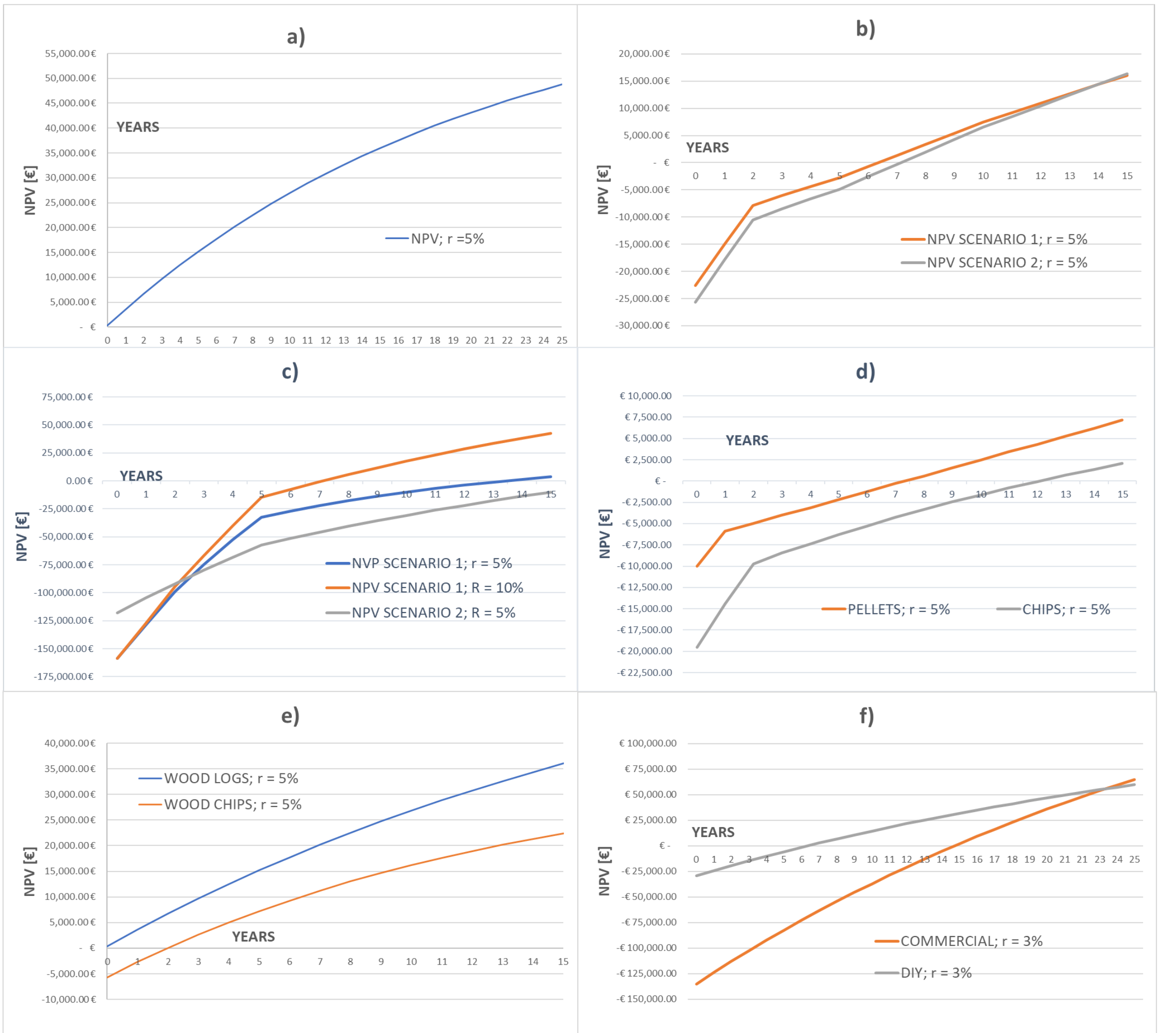

Figure 2. a) **"**Group A" case study: NPV of the investment; b) **"**Group B" case study: NPV of the two investment considered; c) **"**Group C" case study: NPV of the two investment considered; d) **"**Group D" case study: NPV of the two investment considered; e) **"**Group E" case study: NPV of the two investment considered, f) **"**Group f" case study: NPV of the two investment considered.

4. Conclusions

The students' projects showed technical and economical sustainability of RES integration in mountain rural communities. Local wood source (chestnut, oaks and beeches) is the main RES exploited and it also has secondary social advantages such as wildfires reduction, improved forest tourism and local tradition fostering. Photovoltaics applications are convenient when solar radiation is not reduced by close and far shades, however sometimes landscape laws do not permit solar panels installation. In general, high investment profitability is achieved in the case of renovation of existing houses where heat generation with local wood sources is compared with fossil fuels (LPG or diesel oil). For small scale applications (2-30 kW of nominal thermal power), wood logs boilers are the most convenient solution. With an increase of the size of the boiler (up to 100 kW_{th}) also wood chips boilers become convenient, however the cost is higher compared to wood logs because of the chipping phase and the wood chips storages. A possible solution for electrical energy production and consumption in case of restriction to solar photovoltaic installation, is the creation of new energy communities [30] where renewable energy is "shared" between community members. However, the main innovation of this work is the didactic method. This "learning by doing" approach helps the students to acquire independence and to work in a group of future colleagues. Stakeholder interviews, brainstorming and project results presentation to the key actors and teachers are important phases of this approach. At the end, students acquired important technical and soft skills that are fundamentals for their future working careers.

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